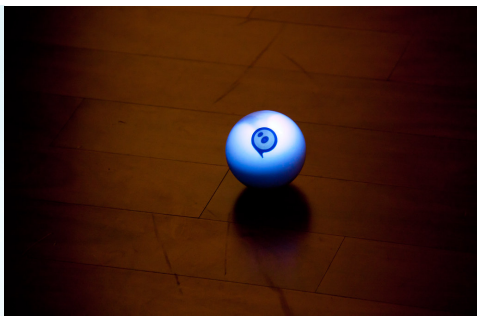
STUDENT
Sochan Mao-ID: 217176271

SUPERVISORS
Dr Mohamed Abdelrazek and Dr Alessio Bonti

EEG Brain Signals, Machine Learning to Control Sphero 2.0

Keywords: EEG, Machine Learning, EmotivBCI Insight NodeJS, Sphero2

(Source: Emotiv Insight)



(Source: "Sphero" by ChrisGoldNY)

Table of Contents

List of figures:

List of tables:

Abstract

Technologies are helpful for people living better, based on modern tools the industrials can produce better and better quality of products. Today, several Machine Learning algorithms have been applied in many areas to solve problems or do the predictions. There are a lot of problems that need AI to help, however several concerns have been raised whether AI can control humans will it a disaster if AI become our enemies. Therefore, some well-known organizations such as Facebook, Microsoft, Neuralink are doing their research on Brain Computer Interface. Their purposes are to be communicate with human brain. This is because, Facebook may need to learn about their users' brain, what people are thinking during surfing on Facebook, Neuralink of Elon Musk may need to include their auto-drive of Tesla with mental commands that car should be able to communicate with human brain to know which direction to wheel a car. Furthermore, it should be a good prevention if technologies can know about the intention of their owners, for example to predict the catastrophe of airplane there have been several researches to learn about pilot' brain by using Electroencephalography (EEG). In addition, it is magnific if people can control their equipment from their brain without use remote control neither smartphones. Imagine if the light is turn of or on by just mental commands, how fast is it, it does not require to walk to press the button, parents will not care about losing their remote controls anymore. Another case, it can imagine about electricity shock, parents can save their toddlers on time in case their kids accident to touch the electric plug by just control to switch off the power. Moreover, according to Australian Network on Disability (2018), there were 4 million disability people in Australia, it was said among five people there is one person who lose their mental or cannot move. It will be an excellent solution to help them be able to move their wheelchairs by using their mental commands. Therefore, this paper will explore more on using EEG Brain Signals to control a Sphero robot by using Emotiv Insight headset. A Cortex model is used to extract commands from Insight in NodeJS, it is using EmotivBCI application of Emotiv to train the commands for PUSH and PULL.

1 Introduction

As to be seen many big companies in the world are researching on Brain Computer Interfaces for many aspects. One part is about to diagnose diseases of brain damages and other related brain issues. Furthermore, in scientific it is to be well prepared to compete with Artificial Intelligent (AI). This is because, AI is become smarter and smarter, so how can human compete to robot in the worst cases. Elon Musk expects that if they find the way to communicate with the brain there might be the possibilities to upgrade human brain to against AI (Grossman, D 2019). It is completely

true; it is a right precaution to against something that should happen in the future. In addition, the universe is huge, what will happening if the extra-terrestrial lives exist, we cannot know about how modern of their technologies, how smart they are, so that will be an advantage of BCI to survive if they find our planet. Hopefully, there will be further progress on BCI due to many organizations in the world are focusing in this area, such as Neuralink of Elon Musk, Facebook, Microsoft, Emotiv, etc. Emotiv is also popular in creating EEG devices and BCI applications, one of their flagship software called Emotiv BCI is helpful to allow developer to work with EEG brain signals and it is free (Chaperon, B. & Chu, P. 2019). According to Gerad, C 2017, Similar project had been done by using NodeJS and Emotive C++ SDK with Epoc+ headset. However, it is complicated to use Emotive Community SDK that mixed NodeJS and C++ libraries to get EEG signals from the headset. This paper will describe about using NodeJS and Cortex V2 with Emotiv BCI to get mental commands from Insight headset to control Sphero 2. Therefore, another part which is working with Sphero 2 API was done by Mr. Miller Wang (Bachelor of Computer 2019).

Figure 1 Emotiv Insight with 5 channels EEG, source Emotiv

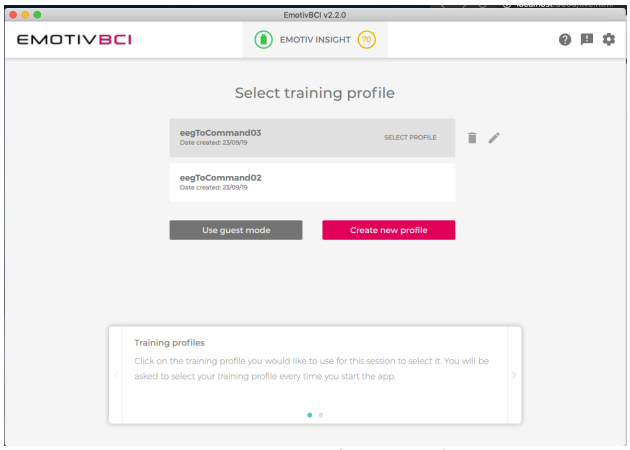


Figure 2 Emotiv BCI to train mental commands

2 Background and Motivation

Human body is a magical machine, there has been for million years ago that our modern human has done the evolution from earlier apes. Among all wonderful organs, human brain is a very complex framework with thousands of building blocks of neurons which are connected like a circuit. Hundreds of years ago that scientists have started to work with brain, until 1924, a German physiologist named Hans Berger had successfully recorded electroencephalography (EEG) on human brain without open the sculp. EEG is one of brain imaging techniques which is cheaper with excellent time resolution comparing to Magnetoencephalography (MEG), Functional Magnetic Resonance Imaging (fMRI) and Positron emission tomography (PET) (Farnsworth, B 2019). EEG Signals have been used for many purposes such as memory recall or human deception tools, fixing brain damages or cure brain diseases.

According to Australian Network on Disability 2018, over four million people in Australia having disabilities. For this reason, are there any solutions to make their lives better? Must they always stay in the bed waiting for their last day. They cannot move their bodies, but they still can use their mentals. Furthermore, they may have their genuine ideas to help the world for instance, Stephen William Hawking, so do not through them away, it is not only about the human right but also the human resources on our globe. So, imagine if people can use their mental to communicate with their relatives, control the modern equipment such as robots, wheelchairs, it will change their life for ever, they will not alone anymore, they can go out, they may join their friends' parties. Moreover, during these days, everyone is running, the kids go to school, wife or husband are busy in work, can disable people taking care by themselves? If they can move their wheelchairs by the mind. In addition, there may be some household robots which can understand their mind, or they can control their robots by the mental commands. It will be the best solution ever to give hopes to disable people in the world. Personally, my grandma who had been taking me since I was born were diagnosed with a disease which she lost her both legs. She cannot walk for several years; it is my dream to have such cutting-edge technology to allow her to move from one place to other. Another expectation is not only moving the wheelchair, can they drive their expensive car? Some researchers are also doing their research to control mobile phone or car from human brain, for instance Neuralink, Elon Musk team is working on Brain Computer Interface (BCI), he may need to integrate his super Tesla car with auto drive from minds. Therefore, if it is success then the disable people can also drive.

Some people are worried about AI is smarter than human being, some researches on human brain are eno outcomes to find the clues to be able to make human smarter to compete with robots or

being a well prepared to against the extra-terrestrial lives which could have more modern technologies if they can find our planet earth before we do. Hence, these results will motivate the scientists getting more progress in BCI.

3 Key research reviews

3.1 Background of Electroencephalogram (EEG)

Electroencephalogram or Electroencephalography (EEG) is an electrical activity recording of human brain to the sculp. It is used to examine the brain damage, epilepsy, sleep disorders, depth of anaesthesia, coma, encephalopathies, brain death etc. (BioPortal 2019 & Wikipedia 2019). The history of electroencephalography started since 1875, at that period the scientists had used it to record the brain signal of rabbits and monkeys. Moreover, EEG was introduced to record the first human in 1924 by Hans Berger, German physiologist and psychiatrist (Wikipedia 2019).

It is reported that the use of EEG has dropped due to the discovery of other techniques like Magnetic Resonance Imaging (MRI) and Computed Tomography (CT). However, EEG is still useful among mobile techniques which can measure millisecond-range of high temporal resolution which cannot be done with CT, PET or MRI (Wikipedia 2019).

3.1.1 EEG Frequency Bands

There are four EEG channels as the following (Chen, J, Wang, H & Hua, C 2018; Priyanka A. Abhang, Bharti W. Gawali, Suresh C. Mehrotra 2016):

Band	Frequency (Hz)	Description
Delta	0.5 - 4	High amplitude of brain wave, it relates to deep sleep stage of NREM or adult slow-wave sleep.
Theta	4 - 8	Feeling sleepy in adults or idling.
Alpha	8 - 12	It found by the founder of EEG (Hans Berger in 1924) and it also was called Berger's wave.
Beta	12 - 35	It is related active thinking, focus, high alert. It is our investigation; can it be memory recall?
Gamma	> 35	This band is related to short-term memory to recognize objects, audios. It is another amazing, it can be related to memory recall but only short-term memory.
Mu	8-12	It might relate to autism.

Table 1 Brain waves (Chen, J, Wang, H & Hua, C 2018; Priyanka A. Abhang, Bharti W. Gawali, Suresh C. Mehrotra 2016)

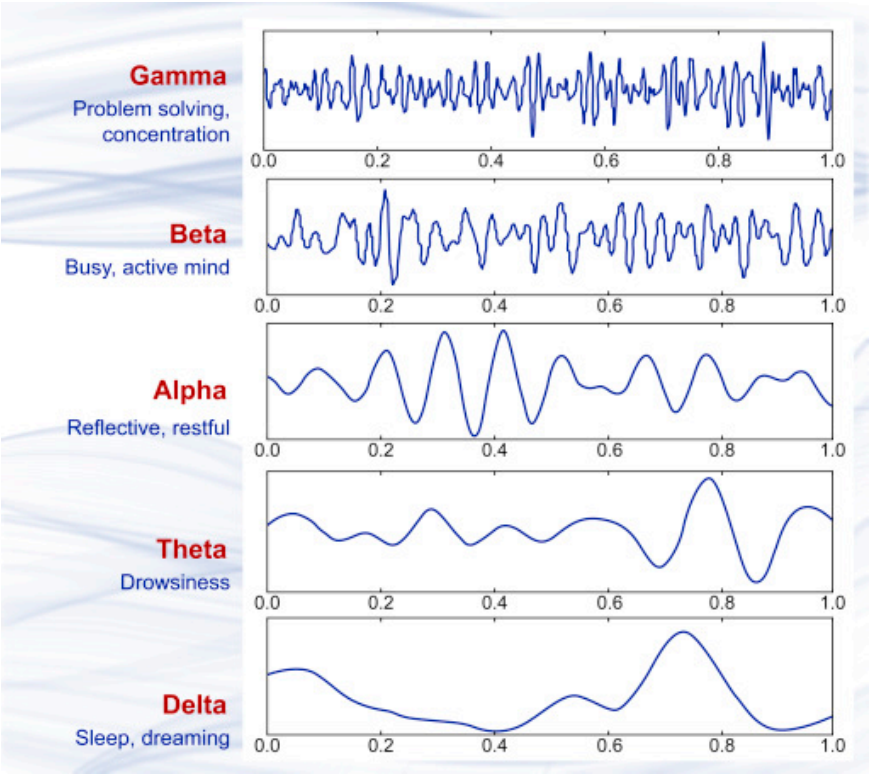


Table 1 Brain waves (Priyanka A. Abhang, Bharti W. Gawali, Suresh C. Mehrotra 2016)

3.1.2 EEG Scalp 10/20 International System

To record EEG signals from human brain with 10 to 20 systems. 10 or 20 here refers to 10% or 20% of distance between front-back or right-left with the channels varied from 32 to 256 (Priyanka A. Abhang, Bharti W. Gawali, Suresh C. Mehrotra 2016).

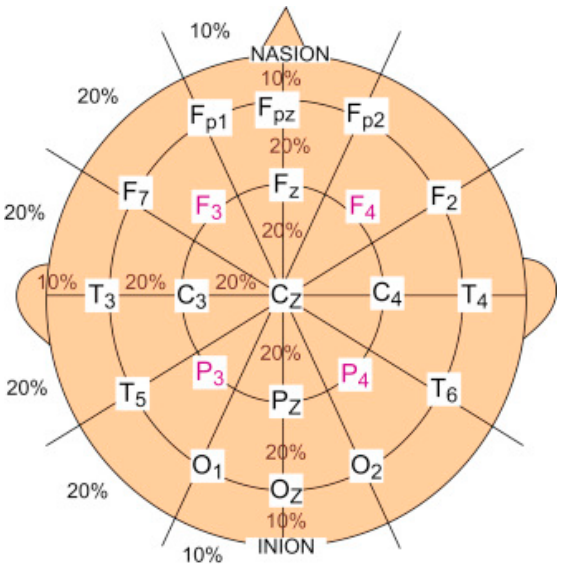


Figure 3 EEG 10/20 international system

3.2 EEG Brain Signals for memory recall

Till now, there were several studies have been done for human deception or lie detection by using different techniques such as Polygraph, magnetic resonance imaging (MRI), Radar based lie detection with ECG and UWB, and heart rate variability (HRV). After describing many existed lie detection techniques with some challenges, they proposed a study to learn human deception by using brain waves or EEG signals. The study was used Guilty Knowledge Test (GKT) to collect input EEG samples. They found that the P300 ERP of EEG brain signal for people who has seen the tested objects (Khandelwal et al., 2016). Surprisingly, Haider, S.K. et al. 2019 stats about the P300 ERP of EEG brain signal for lie detection. Similarly, another paper, Bamatraf, S et al. 2015 had conducted a research article for a system to detect True or False for memory prediction based on 2D & 3D contents with EEG brain signals. They found some different accuracy between short-term memory and long-term memory recall. The found results, for Short-Term Memory (STM) is 96.6 % and for Long-Term Memory is 100% and there is no different between using 2D or 3D objects.

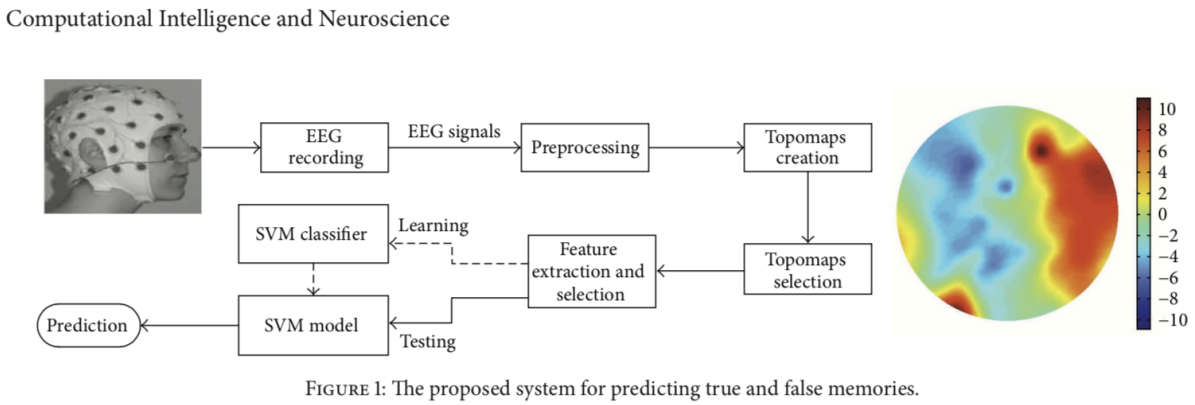


Figure 4 Proposed system for memory recall (Bamatraf, S 2016)

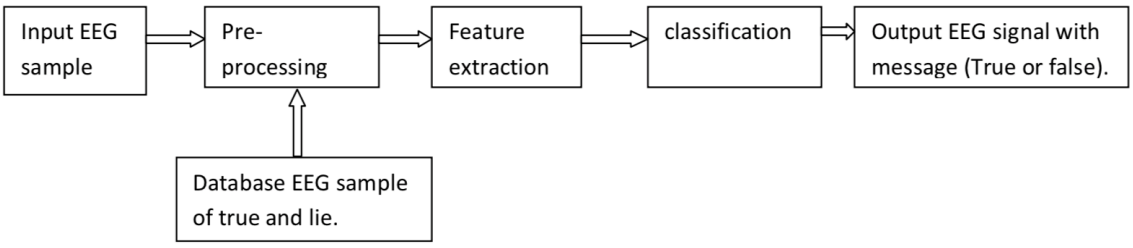


FIG.1 Block diagram of Analysis of EEG Signals for Deception Detection.

Figure 5 System model for Deception detection (Khandelwal et al. 2016)

3.3 Power of EEG for Machine Learning

Several researches have been done to use EEG to help develop useful products as part of Intelligent Artificial or Machine Learning techniques. Below just few examples of plenty human needs about using EEG in the modern approaches.

3.3.1 Helping Pilots' actions for safety flight travelling

During these few decades, there have been several marred news about flight crashes and have been killed several beloved people unexpectedly. So, the researchers have started to look for solutions to prevent the crisis. It is known for sure that only one minute can save people lives, it was amazing that Binias, B, Myszor, D & Cyran, KA 2018 had recently done the research on using EEG brain signals to detect pilots' behaviours, they argued that it requires to use modern equipment to obtain better results for instance EEG headset which have more that 60 electrodes. Similarly, another research, Sauvet, F. et al. 2014 used a single EEG channel to detect the alertness state of flight, their study used EEGLAB in MATLAB. They examined the EEG signals to check whether the pilots are getting asleep or not, they suggested to have an automatic online detection of low-vigilance situations for real flights. Another research, Lai, P. et al. 2017 had used EEG signals to compare the new recruited pilot and experienced one, they found that theta (4-7Hz) for rookie pilots increase comparing to veteran pilots. Therefore, it is really impressed to have smart device to help avoid crisis and EEG is really inexpensive and efficiency to produce that helpful detection equipment for aviation.

3.3.2 Helpful to detect depression

Depression is the most concern in the family, in the community or in the world. This is because, it will be sad in the family if one member get depression, it will make trouble to the society, and seriously to the world. For instance, one case in Cambodia, it calls Khmer-Rouge regime which had killed 3 million people from 1975 to 1979, the survivors are living with depression because of fears of the past shadows. According to Liu, Y. 2017, more than 300 million people in the world are living with depression. Moreover, it is serious if youth get depression in school or at works. Therefore, the researchers have studied about depression by using EEG Brain signals to detect the symptoms (Mumtaz, W. et al. 2018; Sharma, M et al. 2018; Acı, Çİ, Kaya, M & Mishchenko, Y 2019; Jaiswal, AK & Banka, H 2018).

3.3.3 Measure sleep quality

People need their quality of sleep; some people sleep many hours per day but sometimes after they wake up, they are still tired vice versa some healthy people only sleep for few hours.

Therefore, it is about the efficiency of sleeps. According to Tuck 2019, many people have four stages of sleep, those stages are Wake, Light Sleep, Deep Sleep and Stage R. It is said that Deep sleep stage is the restoring stage of our brain and it is known that brain has a slow wave on EEG reading. Moreover, it also states that the last stage is Stage R, the brain is starting to wake, dreams are happening in this stage. People should have more deep sleeps to make them healthy. Consequently, it is really important to know whether they already get into deep sleep, is it good to let the sleep prolong into Stage R? This is one of the reasons that people got exhausted though they have slept for long hours. A research was done in 2016 to measure the score of sleep based on EEG brain signals (Peker, M 2016).

3.3.4 Visualize EEG and Machine Learning

It is surprizing that EEG has been used for identifying the individual like fingerprints or facial biometrics (Valizadeh, SA et al. 2019). Moreover, Al Zoubi et al. 2019 stated about using EEG Brain Signals with machine learning to detect ages. They found that Beta channel at TP9 is crucial to detect human age, and the result was not dependent on male neither female. Another amazing study, Schirrmeister et al. 2017 studied to use EEG Brain signal with machine learning framework to allow the disability people who cannot talk to communicate with others via Brain Computer Interface (BCI). They were focusing on ConvNets performance to do the visualization of EEG brain signals.

3.3.5 Help monitor or take care people

EEG brain signals with Machine Learning are more helpful in hospitals or taking care people (age care or childcare centres). According to Kiiski et al. 2018 found the potential of Event-related potentials (ERPs) to predict mental performing of multiple sclerosis (MS) patients. They suggested to create application based on ERPs to help clinicians to predict patient status in one or two years later. In addition, Fernández et al. 2018 expressed about predicting the mortality of children in intensive care unit (ICU) from unexpected illness. Their results show that 13% to 14% of critically ill children are facing the short-term mortalities, they also mentioned about the benefits of machine learning techniques in helping improve the effect prediction in the ICU.

3.3.6 EEG datasets or models for Machine Learning

The following are some existed EEG datasets or models with Machine Learning techniques:

3.3.6.1 Emotive Cortex API

Cortex is an API which supports both Windows and macOS, it is a WebSocket server based on Json-RPC protocol. Within an EmotivID, it allows to connect with the basic data of motion data,

metal Commands, facial expressions, performance metrics, frequency bands, contact quality and battery level. However, to access EEG data, it requires a paid subscription (Chaperon, B. & Chu, P. 2019). There are Cortex Version 1 and Version 2. There are examples for how to use the API, it is supporting C++, NodeJS, Python, CSharp (C#). It is amazing to have been supported in NodeJS or JavaScript, that will be useful in some IoT applications.

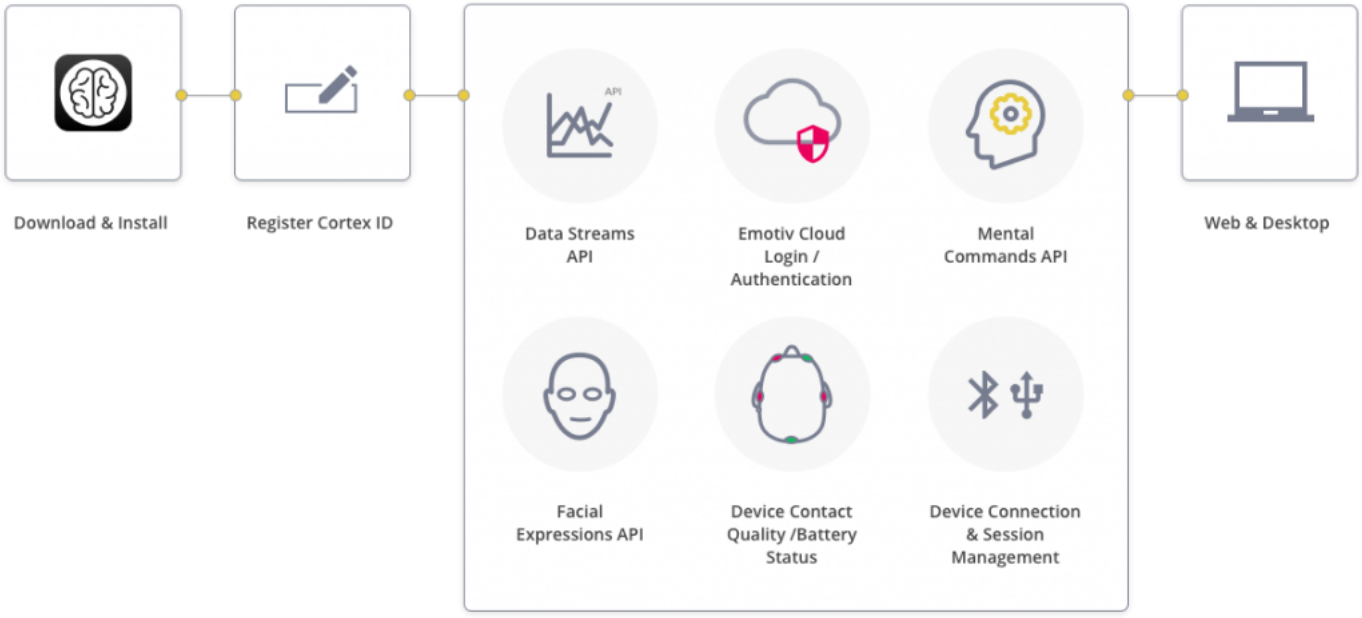


Figure 6 Source Imotiv Developer

3.3.6.2 Emotiv C++ SDK

This project was done in 2015, it was using NodeJS and C++ SDK (Gerard, C 2015). However, it tested with Emotiv Epoc, it does not work with Insight yet. Furthermore, it required Emotiv Community SDK v3.4.0 and many configurations. For this circumstance, following all steps as described in readme but it is not successful to run the project, maybe it requires Epoc to run it, at the moment we have only Insight.

3.3.6.3 Public repositories in Github

According to Github 2019, there are thirty-nine of public repositories related EEG signal classification and Machine Learning. The most voted model is Arl-EEGModels which is done by the Army Research Laboratory, it is using Keras and Tensorflow with Python. Those models are implementing in Python, MATLAB, HTML, JavaScript, C#, C, TeX. Notably, Python and MATLAB are using the most in many models.

3.4 Short-Term Memory (STM) and Long-Term Memory (LTM) Storage

Human brain is magic that can store a lot of possible data for the entire life. People see or heard somethings then keep them into the memory. Therefore, there are two ways to remember all seen activities, according to Bamatraf, S et al. (2016), human storage consists of Short-Term Memory (STM) and Long-Term Memory (LTM). Several studies have been proved how human remember short-term memory and long-term memory (Cowan, N 2019; Yamagata, N et al. 2015 & Nie, J 2019). Several questions have been raised, is it possible to retrieve or transfer human memory into computer? (Neuralink 2019; Shankland, S 2019). Moreover, several researches have been done about Electroencephalography (EEG) Brain Signals to see the different states of a human brain based on seeing object or current activities. In addition, the researchers are also doing researches based on EEG Brain Signals to see human deception, to investigate crime (Khandelwal, R.J. 2016).

3.5 EEG Datasets and Tools

- Free EEG datasets with EEGLAB software by Swartz Center for Computational Neuroscience (SCCN 2019). It consists of many datasets related to EEG Brain Signal experiments, one of them related to memory recall which was recording the EEG signals of participants to recognize the photos.
- EEG datasets in Github (Agarwal, M. 2017).
- Temple University Hospital EEG (TUH EEG) Resources, here it consists of more than 30, 000 EEG data experiments which have been collected since 2002(Tuh EEG 2019).
- EEG Data Downloads of Child Mind Institute (Child Mind Institute 2016).
- Open source software to analyse EEG signals (Researchgate 2018). There are several open source tools to be used for analysing EEG signals, for instance MNE with Python, EEGLAB in MATLAB etc.
- OpenVibe by Laurent Bougrain, it described about many areas of applications which are used EEG or brain images such as nutrition, finance sector (neuroeconomics, neuromarketing), education (thoughtful games), Human Computer Interface (affective computing, multimodal interaction), safety & security (forensics, military, process control), entertainment (game, art), science (real time analysis) and health sector (assistive technologies, therapy, monitoring, prevention, wellness, addition disorders etc.) (Bougrain, L 2017).

3.6 Evaluation and Motivation

To sum up, Electroencephalogram (EEG) is inexpensive with high resolution compare to other brain imaging. EEG have been used in machine learning for many purposes such as in aviation, to

help detect depression, to measure sleep quality, to visualize EEG signals, it is helpful in working with machine learning to help health care or taking care people. Moreover, EEG brain signals were used to detect people deception for memory recall. However, some studies did not show clear results, for example Binias, B, Myszor, D & Cyran, KA 2018 had done a study to use EEG Brain Signals to predict the pilots' status before some unpredicted chaos happening. However, they mentioned that cannot implement it in the real situation. Further, some studies have been failed due to not sanctified EEG recording devices. Therefore, this paper will show all related use cases of EEG signals in Machine Learning, it also listed the available EEG datasets and tools to analyse EEG Brain signals.

4 Problems and analysis

During these days, it is a boom of technologies, people are living with modern devices such as smart home, smart phones, 3D-Games, robots for household etc. However, it is very sorrow one to the disable people who cannot use their hands neither their legs. Some people were born without hands or legs, some were lost because of diseases, they have difficulties to move, they cannot enjoy new games or event cannot communicate with the robots. Hopefully, the disable people cannot use their mind to control the modern equipment, playing games, move their wheelchair around, etc. So, here we study to see the possibilities to use Emotiv Insight to communicate with computers. There must be faire living lives for everyone who were born on earth just only some decades, so be joyful on earth together.

4.1 Control robots with mind

Nowadays, many modern robots have been invented for different purposes, it was estimated that there were around 4 million services of robots in 2006 (Gates Bill 2007). Some robots can help in household to clean up the house, for instance Xiaomi Mi Roborock S6, Roomba Vacuums which can help people to clean carpet on the floor. Furthermore, some robots have been used as a care-taker that can communicate to people, they have got the cameras which can capture and analyse the seen objects, so if disable people can talk to those robots via their minds and maybe those robots can understand what disable people are thinking or the robots can get the emotion of the owner that they are being stress, unhappy or being at risk which need emergency help, the robots can send the notification to friends, relatives or related agencies for help. Consequently, it will be brilliant to control robots via mind, disable people will not be alone anymore, they can enjoy their daily lives like normal people.

4.2 Playing modern games with mind

Over the past century, games are also one of people entertainment options beside music and movies. Some modern games were built to allow people to experience some daily life. Moreover, some games can teach kids to learn maths, colours, words etc. However, it is horrible that disable cannot enjoy those interested games because they cannot move or use their hand properly. Imagine, if they can use their minds to play those games instead of their hands, it will be awesome, is it possible to use Emotiv Insight to play games.

4.3 Moving wheelchair with mind

One reason for this gap is that it is indeed for disable people. Handicap people cannot use their body appropriately. Therefore, it is another huge advantage which can change their sorrow lives by being able to move their wheelchair by their brains. It will change their life completely, disable people will be able to move around by themselves, their hopes are coming back due to the modern wheelchair which can be controlled with brain.

5 Method

A literature review about using EEG for Machine Learning has been done, it is found that many areas have been used EEG and Machine Learning such as Healthcare, Scientific, Software Development, etc. As mentioned in Literature Synthesis, there had been some researchers used Emotiv headsets (Epoc+ or Insight) to control robots. However, the existed solutions were complicated, for example Gerard, C 2017 had implemented an addon to NodeJS for Emotiv C++ SDK, but it requires many configurations and it is not successful to run the project to see the experiments. Therefore, a model is implemented to use NodeJS, Cortex.js and Emotiv BCI to control Sphero 2. Two commands were trained in Emotiv BCI to test with Sphero 2.0 API.

A simple user interface was created to test the output from Emotiv Insight in NodeJS, during the execution Node Server starts to connect the headset and record the signal from Insight into JSON file for every ten seconds. This is because, the signals produced from the headset is very quick, just a millisecond there are many streamed data. The experiments were started by training Emotiv BCI to recognize the mental commands for PUSH and PULL. Meanwhile, several trainings have been done, surprisingly, a trick was found to make the stream output accurate, it also related to memory recall, so it is about the moment of training and during the use of the mental commands which will be described in the analysis.

6 Experiment and result

6.1 Setup Emotiv Insight

6.1.1 Insight Specs

Insight specs are the following:

EEG Sensors	EEG Signals	Motion sensors	Detections	Connection
5 channels: AF3, AF4, T7, T8, Pz	**Sampling rate:** 128 samples per second per channel	**IMU part:** ICM-20948	**Mental commands:** neutral + up to 4 pretrained items per training profile	**Wireless:** Bluetooth Low Energy
2 references: CMS/DRL references on left mastoid process	**Resolution:** 14 bits with 1 LSB = 0.51μV	**Accelerometer:** 3-axis +/-8g	**Performance metrics:** Excitement, Engagement, Relaxation, Interest, Stress, Focus	**Includes proprietary USB receiver:** 2.4GHz band
New three prong gummy sensor: for better hair penetration on Pz	**Frequency response:** 0.5-43Hz, digital notch filters at 50Hz and 60Hz	**Gyroscope:** 3-axis +/-2000 dps	**Facial Expressions:** Blink, Wink L/R, Surprise, Frown, Smile, Clench	
Sensor material: Hydrophilic semi-dry polymer	**Filtering:** Built in digital 5th order Sinc filter	**Magnetometer:** 3-axis +/- 12 gauss		
	Dynamic range (input referred): 8400 μV(pp)	**Sampling rate:** 64 Hz		
	Coupling mode: AC coupled	**Resolution:** 14 bits		

Table 2 Insight specification (Source: Emotiv Insight Specs)

6.1.2 Register and Download Emotiv Apps

Emotiv Insight is cheaper than others, it has only five channels, AF3, AF4, T7, T8 and Pz as shown in below figure. Insight can be used for numerous features such as to be streaming raw EEG, to be used for extract the mental commands, performance measurement (stress, engagement, interest, relaxation, focus and excitement), to work with frequency bands, facial recognition expression and also can be detected user emotions. The sensors AF3 and AF4 for frontal channels, T7 and T8 for left and right sides, and the last one is Pz is back cortex. Some researchers showed that front cortexes related to memory recall (Noh, E et al. n.d.).

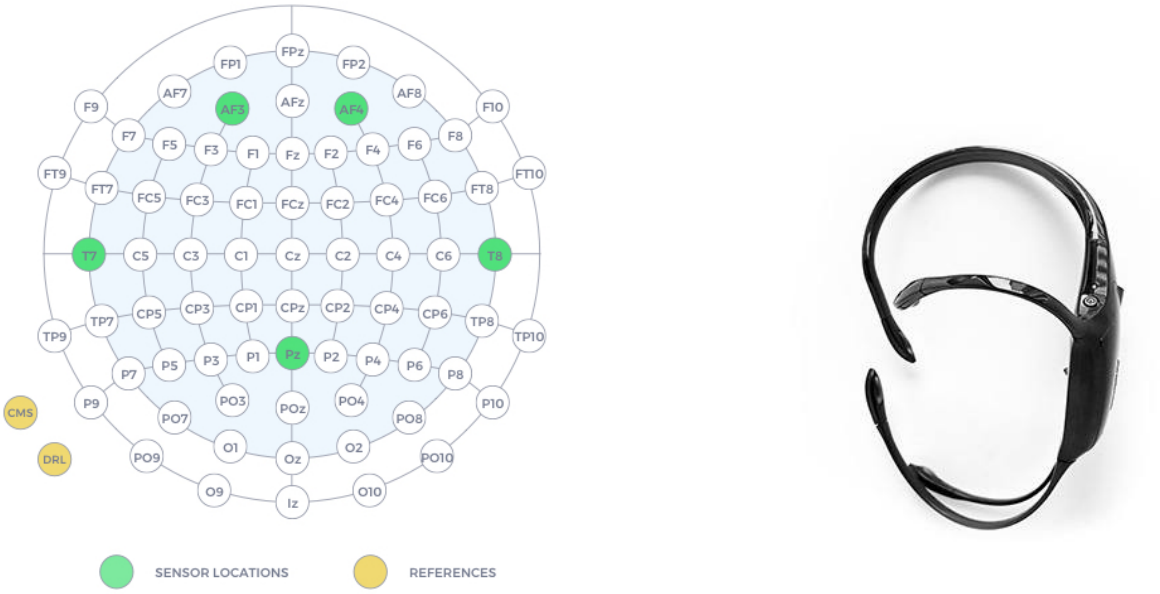


Figure 7 Insight 20-10 sensors (source: Emotive)

Insight is working with Bluetooth; however, it cannot connect it directly, it requires to follow the developer instructions in Emotiv Developer as shown in the below figure.

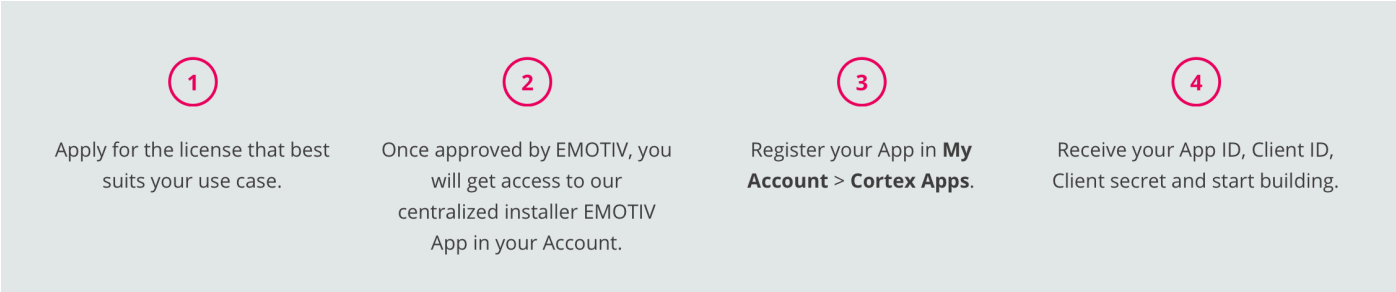


Figure 8 Emotiv Developer, follow the steps to create your own cortex application

1. Register a suitable license, for instance the free version allows developer to use Emotiv BCI, this project was used the free version.
2. After approved, in my account to browse for free Emotiv App for appropriate operating system, for example here is Emotiv for Mac.

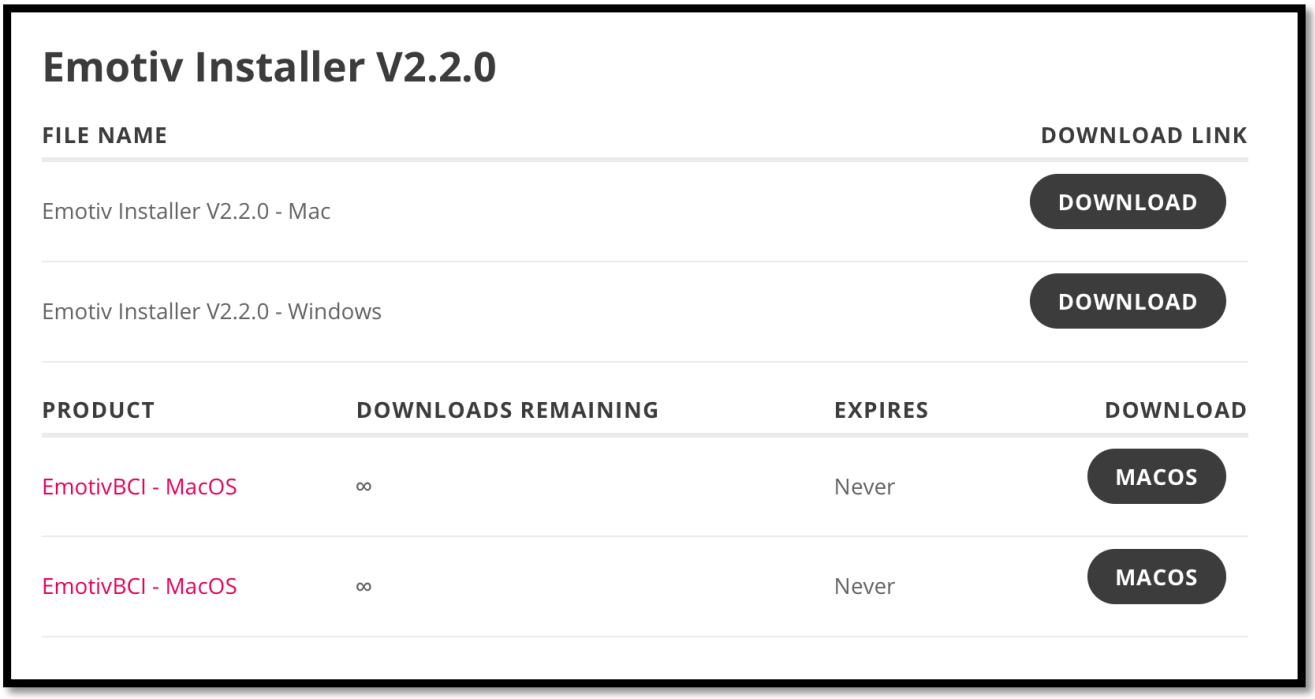


Figure 9 Download Emotiv applications

3. Register your application to get authentication to use in Cortex.js which will be under Cortex Apps

Figure 10 Example of Cortex app registration

4. Build your Cortex Application with received Client ID and the password or secret.

6.1.3 Emotiv machine learning to train mental commands

Via Emotiv, it is known as three different ways to train Emotiv headset to understand the user mental commands, for advance users, Emotiv recommends to user to use Software Development Kit (SDK) called Cortex, and other two ways by using Emotiv BCI and Node-Red Toolbox.

Firstly, it can be done by Emotiv BCI application, it is free of charge which allows developer to work on mental commands, facial expression, etc, it is supervised learning algorithms. This is because, it requires a specific profile to produce the mental commands in the application.

Secondly, it is about unsupervised learning, it trains the headset during its experiment but due to time constraints it was not explored in deep about how to use it. Therefore, it is really useful if the application needs to be used by multiple users then its accuracies will be upgrade from time to times, it means it can train by itself during the uses of the application.

Finally, Emotiv suggest user to use a third-party service of Node-Red which is called Node-Red Toolbox. User needs to install Node-Red locally or via cloud services. Consequently, EmotivBCI and Node-Red Toolbox are prebuilt services which users can reuse to create their own BCI applications.

In this paper, it is using Emotiv BCI to train the mental commands due the limited time.

6.1.3.1 Training mental commands with Emotiv BCI

This is one part of the project to work with mental commands. It is using Emotiv BCI to train the mental commands. Basically, the predefined commands in Emotiv BCI are PUSH, PULL, LIFT, DROP, LEFT, RIGHT, ROTATE LEFT, ROTATE RIGHT, ROTATE FORWARDS, ROTATE BACKWARDS, ROTATE CLOCKWISE, ROTATE ANTICLOCKWISE, DISAPPEAR. However, developers need to train those commands to be used in the applications.

Emotiv BCI, can be downloaded for free after register with Emotiv.com. So, to train each mental command is to follow the bellow steps:

1. **Power on** the Insight and put it on to experiment.

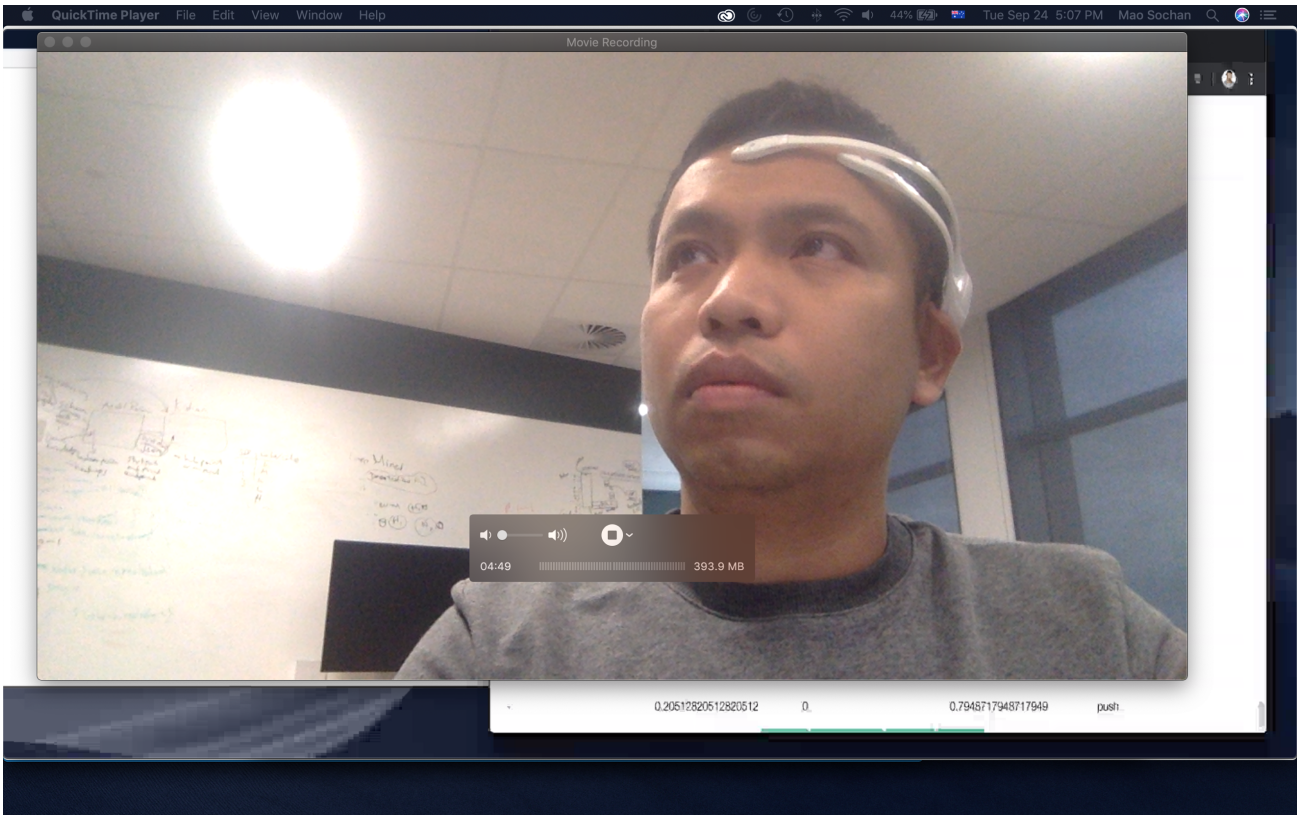


Figure 11 Put on the Insight

2. **Connect Emotiv headset**, this headset is working with low energy Bluetooth device, it does not paire directly like other devices. It required to connect via Emotiv application. EmotivBCI is one of Emotiv

applications which can be used to connect Emotiv headset to computer. This paper was described about working with Insight in Mac.

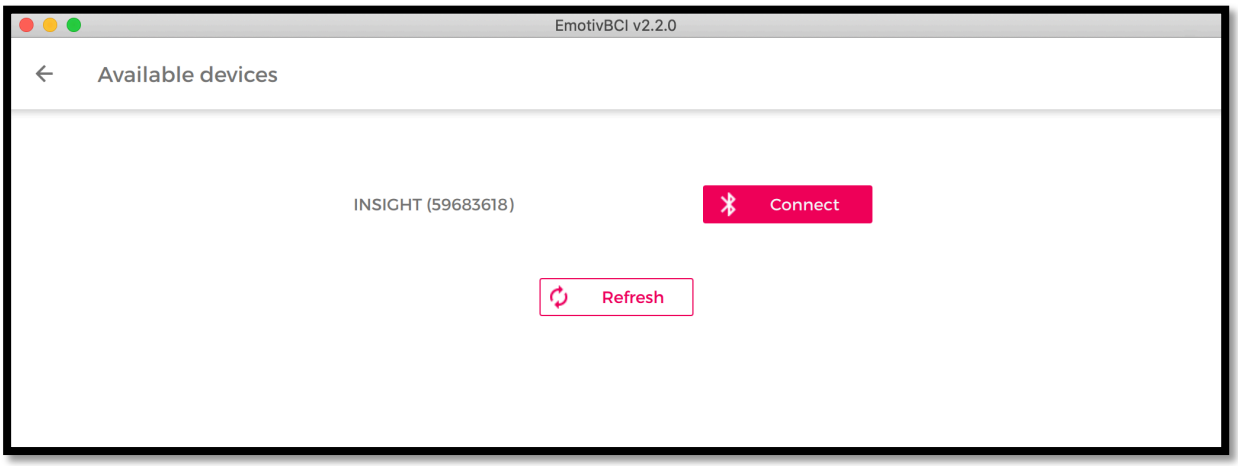


Figure 12 Connect Emotiv headset

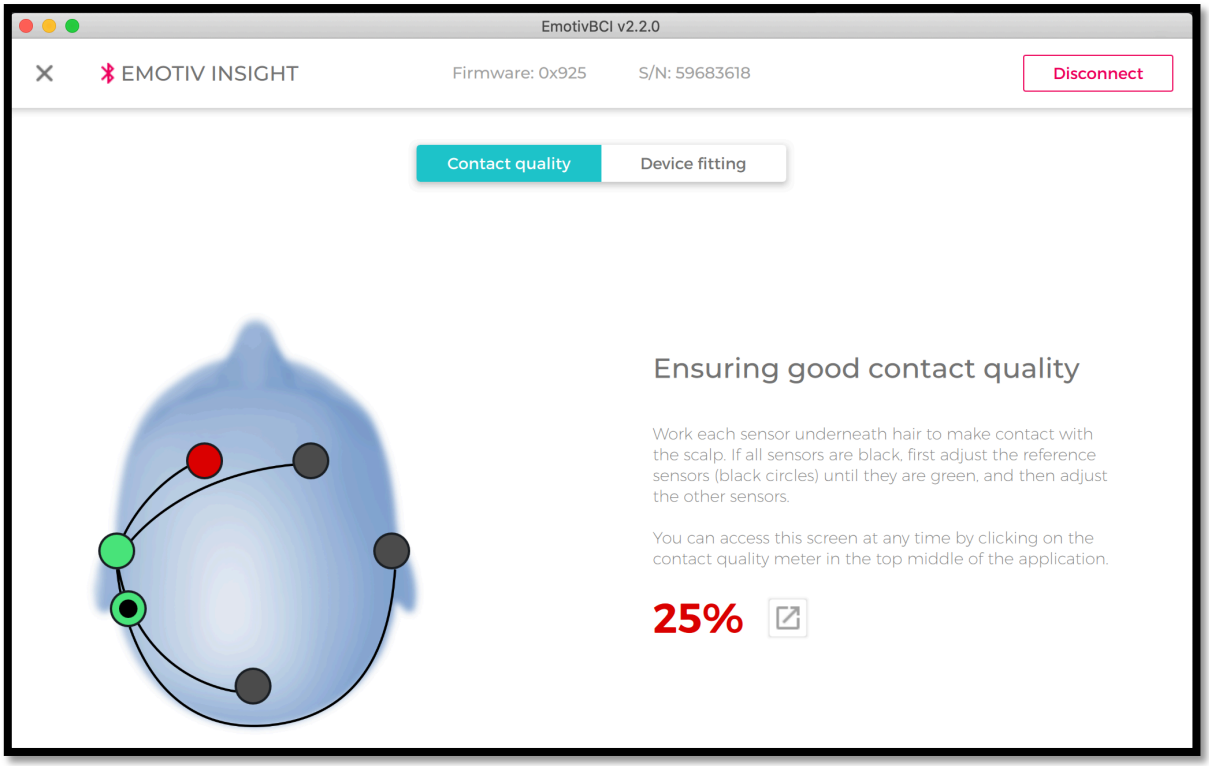
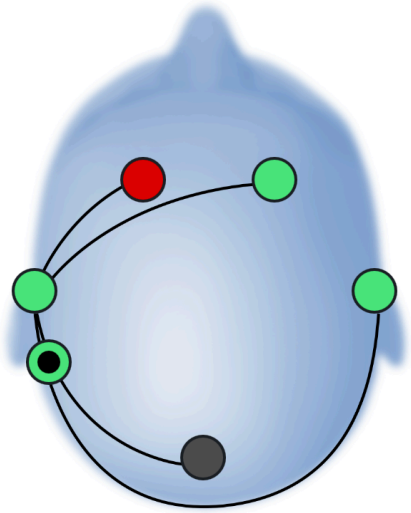


Figure 13 Connected Insight with MAC OS

3. As shown in below figure, all sensors should be green to get better responded results. Basically, there are four colors while a user is putting on the headset as the following:
    a. Gray: no signal, it is not correct to the sensor; user needs to move the headset until it change to other color.
    b. Red: bad, it starts to recognize the sensor but need to move a little more to change to orange.

c. Orange: poor, it is fitting but it is not perfect, user needs to move the headset a very little to get green color.

d. Green: good, it is perfect sensor fitting, it recommended to have green to get perfect results.



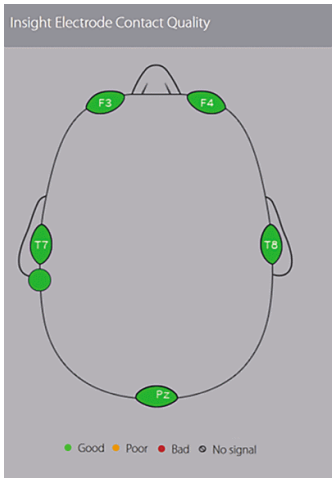


Figure 14 Insight electrode contact quality (source: Benjamin Perkins)

4. **Calibrate** the headset to get the quality contacted ele successfully, it needs to calibrate the headset to fit with all electrodes and it is said that it should be 95+ matching quality to start train commands by following the instructions written in the box. However, these stimuli have got very little chance to get all matched electrodes, only eighty percent of contacted electrodes.

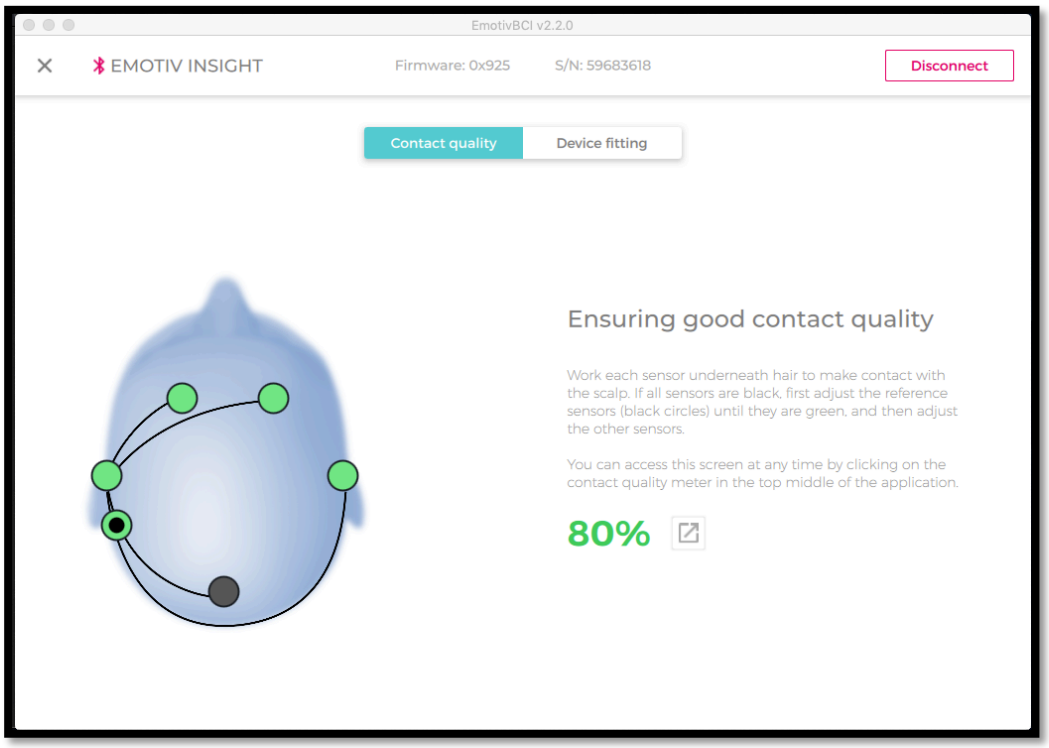


Figure 15 Contact quality of electrodes

5. **Create new profile,** it requires to have a profile to train the commands, this profile will associate the user account of Emotiv and save to the cloud. During the testing, it needs to select a profile to work with otherwise it does not work.

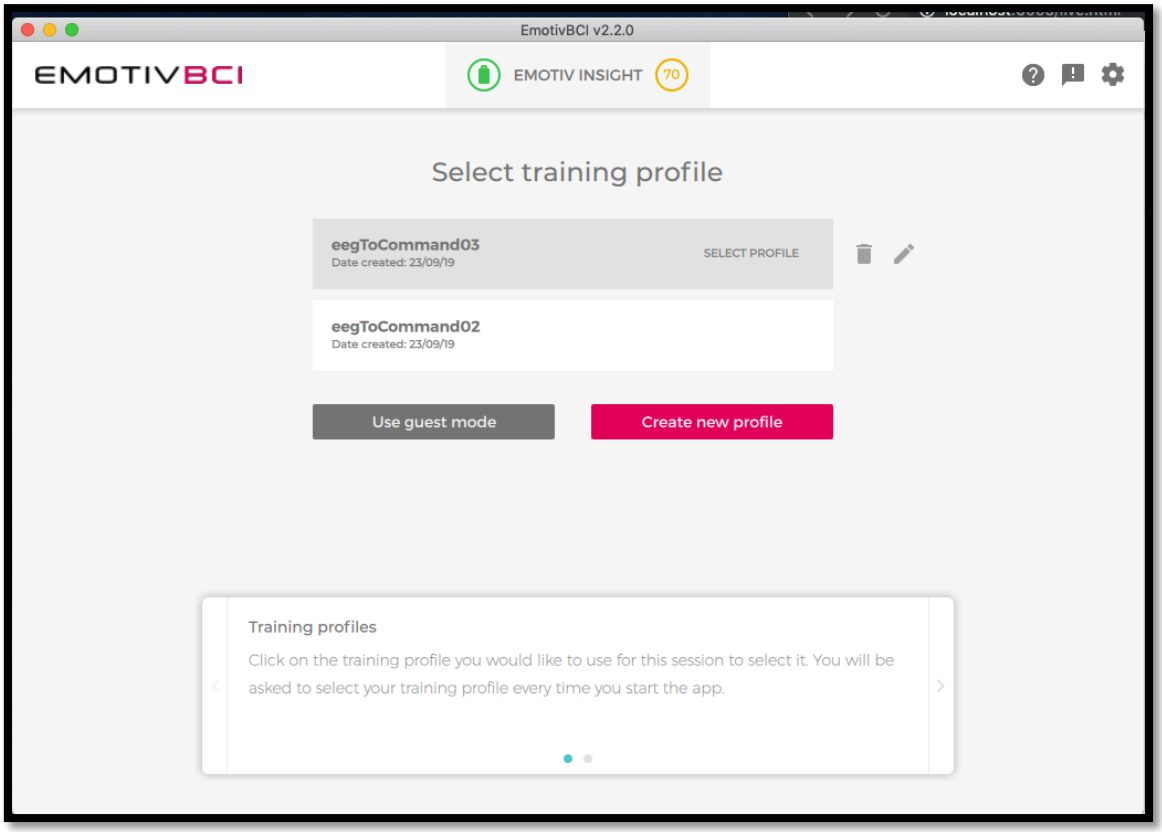


Figure 16 Create new profile or select an existed to train mental commands

6. **Start to train** the mental commands, the first training is **NEUTRAL** before unlocking to train the first command. NEUTRAL is a based brain signals which is clear or in this study is about to stop the Sphero. Several profiles have been tested to see the best performance, then useful tip coming for how to form all commands into different scenarios. For instance, the tested commands are PUSH and PULL, it is a lesson learned about how to use EmotivBCI efficiently. In Figure 17, it shows that the train signals are almost the same, this will produce the ambiguous between those mental commands. However, Figure18 shows the different mapping of PUSH and PULL, that is the reason the successful output mental commands were produced during the stimuli.

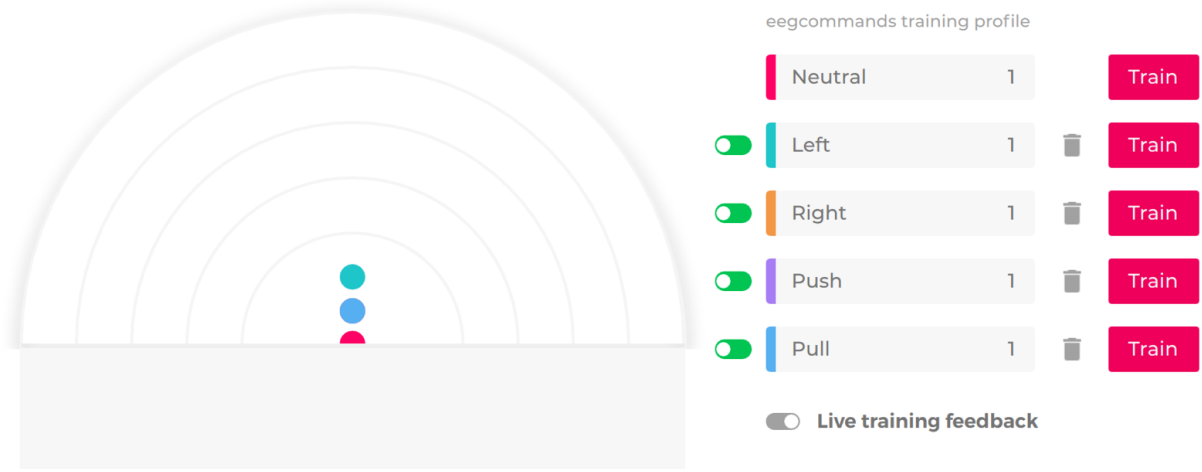


Figure 17 Fail Tested BCI training profile

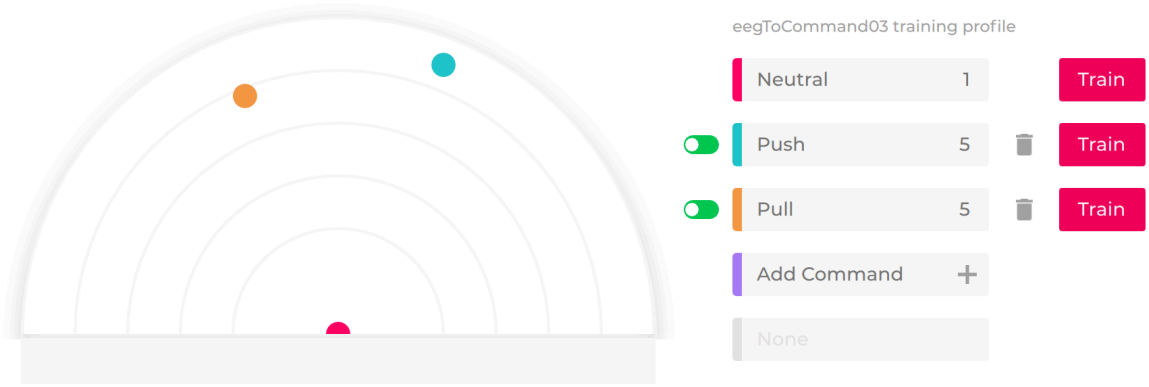


Figure 18 Success tested training profiles

The training mental commands are the most challenge which need to make it attentively. Hence, during every training, it must keep an eye on the headset contact quality, it must be above 80% and the quality of training as well. As shown in the Figure 19, it must be accepted training quality, it must be some sort of the trainings which said at least “this training is ok”, then click to accept.

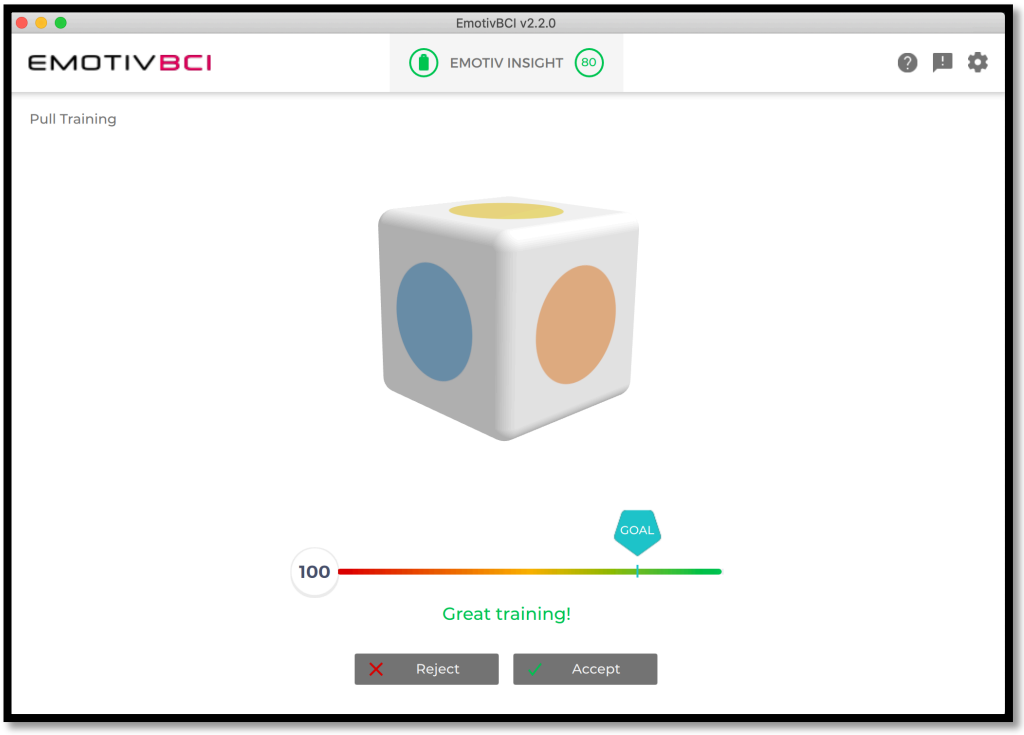


Figure 19 Quality of training goal to be accepted

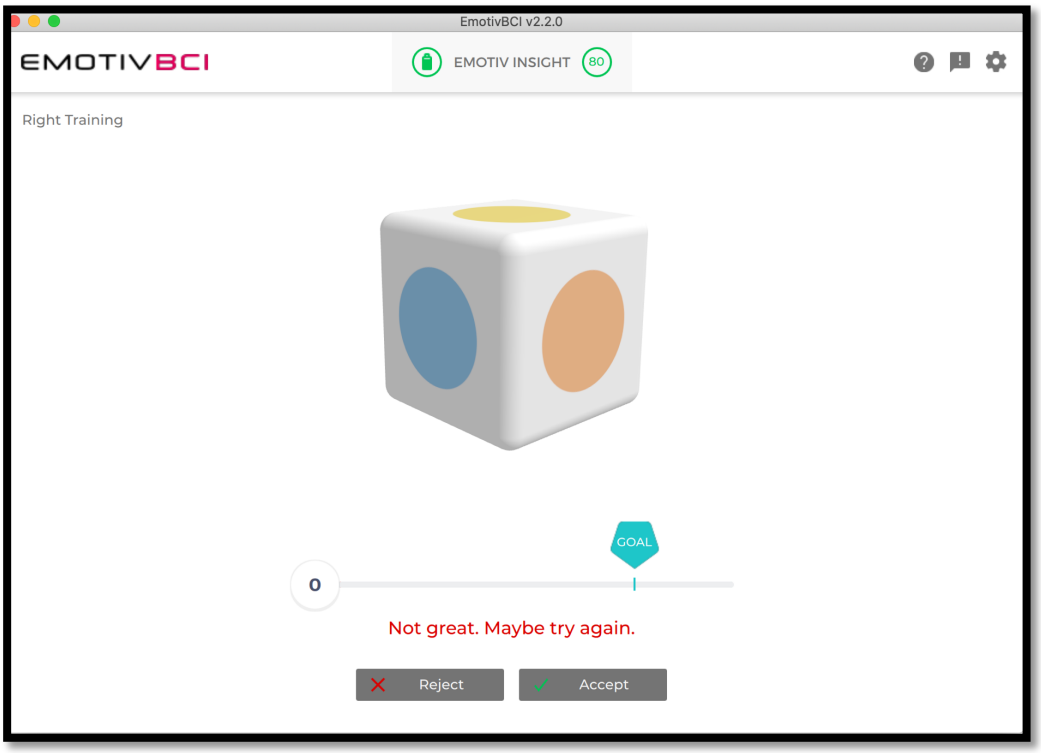


Figure 20 bad training which should not accept

During the last experiment, the result was magnific because the robot was control successfully, please see the demo and Github. Consequently, the hint to success is to imagine about the reality of each mental command, for example, it is training PUSH, user must think about to push something or push the actual robot. In the training, EmotivBCI uses a cube to train user minds, for example to train PUSH, the cube moves forward from a location to other, the cube size that user is seeing is changing accordingly from big into small. Then during the use of calling command PUSH, user should imagine the movements of the cube for PUSH then vice versa for PULL. For every accepted training, each command will be increased its capacity, so it is recommended that each mental command should be trained for a period of time before starting a new mental command. Another observation, a profile was trained and produced very good result, but it became to not recognize the mental commands, it does not produce PULL neither PUSH due to user tried to train more NEUTRAL commands. Moreover, after each training, user can also test the current training command with LIVE MODE.

6.1.3.2 Training profile with Cortex API

Emotiv API allows developers to train Mental commands without using Emotiv BCI application. However, due to the limited times, it was not yet explored further, it can be called in Machine Learning that Unsupervised Learning that benefit to several users' profiles. It means the developers will not use Emotiv BCI to train BCI profile to be used in the application, the developers can create their own algorithms to work with their BCI application. The main points are status, action and result please see Developer Tutorial. Moreover, it is working with "sys" data stream. Please also see training workflow explained from Emotiv to train a mental command.

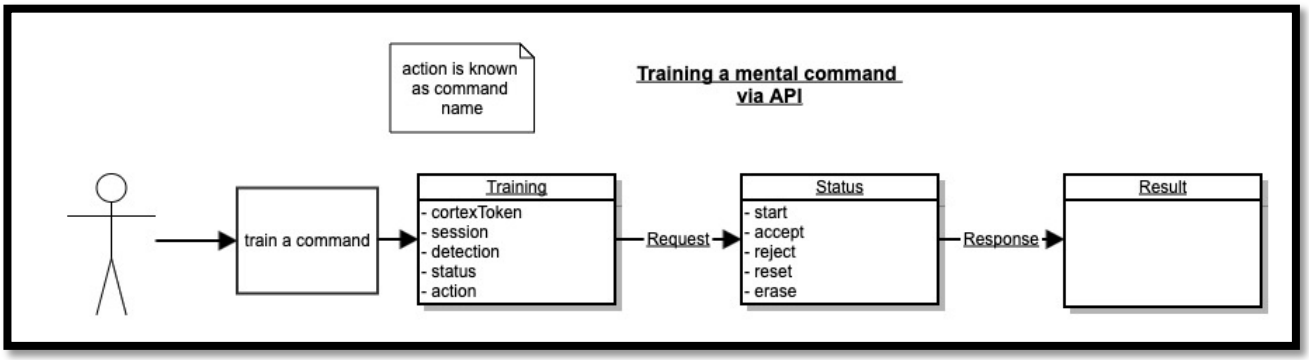


Figure 21 Train a mental command by API

6.1.3.3 Train Emotiv headset with Node-Red Toolbox

Node-Red is a prebuilt service which developer can use it to design their application with less codes, it is very popular in develop application by using cloud services, for instance IBM cloud. Therefore, Emotiv also include their service in Node-Red which user can just drag a ready service to build their BCI application, it is working the same to Emotiv SDK and EmotivBCI.

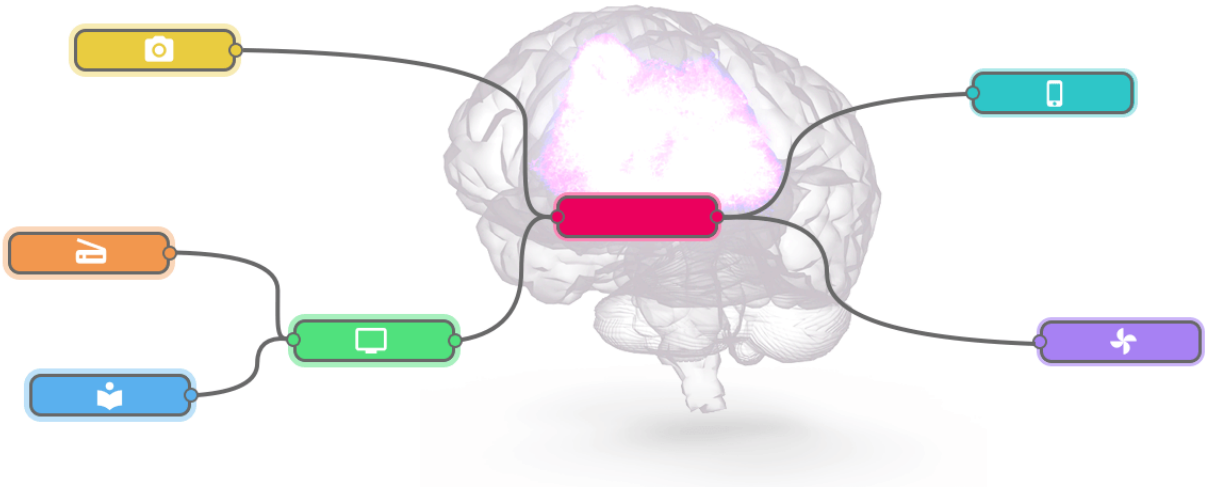


Figure 22 Build BCI Apps with Node-Red Toolbox (Source: Emotiv Node-Red)

6.2 NodeJS client and server to handle EEG mental commands

To test these stimuli, a NodeJS project was implemented which consists of Backend and Front-end. Cortex SDK is working with Web Socket, it needs to run `npm install ws socket.io-client` with Cortex SDK Version 2.0 and `npm install axios` to use axios to connect RESTful API of Sphero 2.

6.2.1 Software Development Kit (SDK) V2

Emotiv SDK was changed from V1 to V2, its main processes are Check login and access, Get session info and Subscribe data stream. There are many options to subscribe data stream such as 'fac', 'pow', 'eeg', 'mot', 'met', 'com'. This paper it is using 'com' to subscribe data from EmotivBCI which already described in 5.2.3.1.

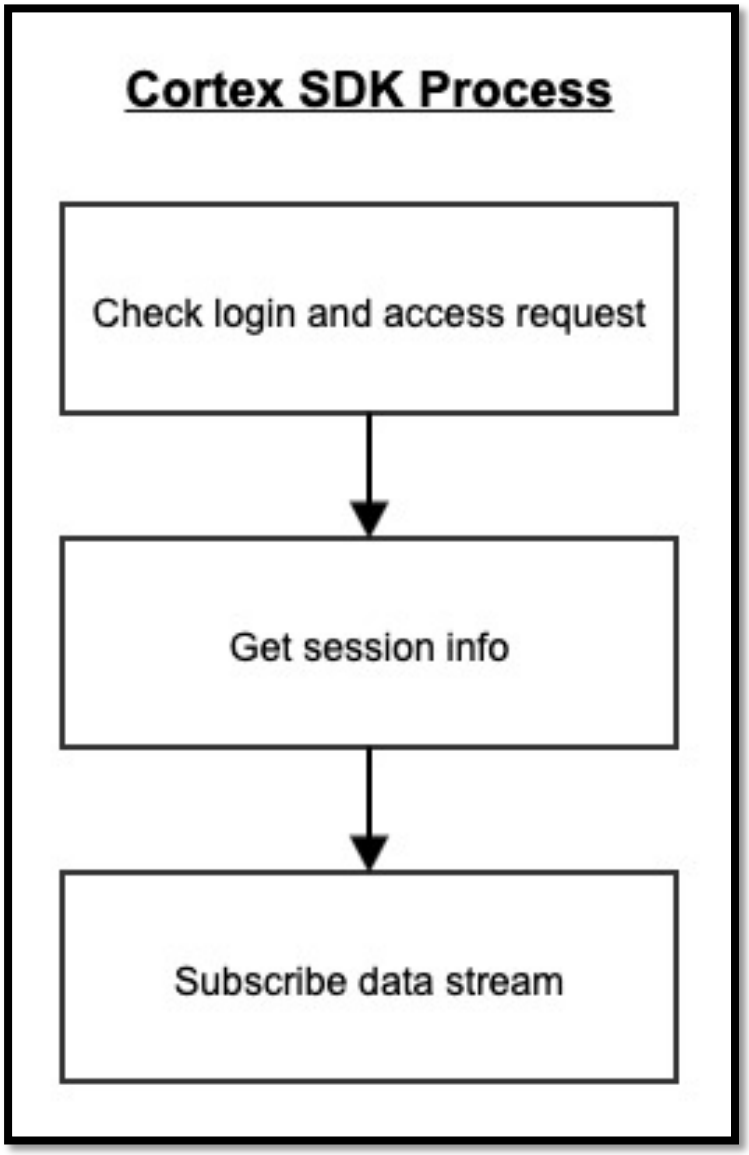


Figure 23 Cortex Version 2 processes

Check login and access request

After registration of the application via Emotiv.com, developer get Client Id and Secret to be used to request Cortex API.

```
requestAccess() {
    const REQUESTACCESSID = 2;
    const { user } = this;
    const requestAccessRequest = {
      id: REQUESTACCESSID,
      jsonrpc: '2.0',
      method: 'requestAccess',
      params: {
```

```
        clientId: user.clientId,
        clientSecret: user.clientSecret,
      },
    };
```

Get session info

Next step is about session to handle the tasks between Cortex and Insight, it requires a session which have been used the following script:

```
createSession (authToken, headsetID) {
    const CREATESESSIONID = 4;
    const createSessionRequest = {
      jsonrpc: '2.0',
      id: CREATESESSIONID,
      method: 'createSession',
      params: {
        cortexToken: authToken,
        headset: headsetID,
        status: 'open',
      },
    };

    return new Promise(((resolve, reject) => {
      socket.send(JSON.stringify(createSessionRequest));
      socket.on('message', (data) => {
        try {
          if (JSON.parse(data).id === CREATESESSIONID) {
            const sessionID = JSON.parse(data).result.id;
            resolve(sessionID);
          }
        } catch (error) {
          console.error(error);
        }
      });
    }));
  }
```

Subscribe data stream

Finally, it is about streaming data from Insight, the Node Server save the received data buffer into a JSON file, this project it called info.json. Please see the following script to subscribe a data stream, it is streaming ‘com’.

```
unSubscribeRequest(streams, authToken, sessionID){
    const UNSUBSCRIPTIONID = 6;
    const unSubscribeRequestReq = {
      id: UNSUBSCRIPTIONID,
      jsonrpc: '2.0',
      method: 'unsubscribe',
      params: {
        cortexToken: authToken,
        session: sessionID,
        streams,
      },
    };
    socket.send(JSON.stringify(subscribeRequestReq));
    socket.on('message', (data => {
      try {
        console.log(data);
        resolve(data);
      } catch (error) {
        console.log(error);
      }
    }));
  }
```

6.2.2 Application structure and model

As shown in the below figure, at the start of NodeJS Server, it communicates with headset to stream ‘com’ data and save to json file which flushes for every 10 seconds. Front-end requests Node Server for streamed data from JSON for every three seconds then analyse for PUSH or PULL. After it gets PUSH or PULL as value 1 or -1, the front-end post the command value to Node-Server. Finally, Node-Server will post the received command to Sphero at ‘/api/control’ to control Sphero to go forward or backward.

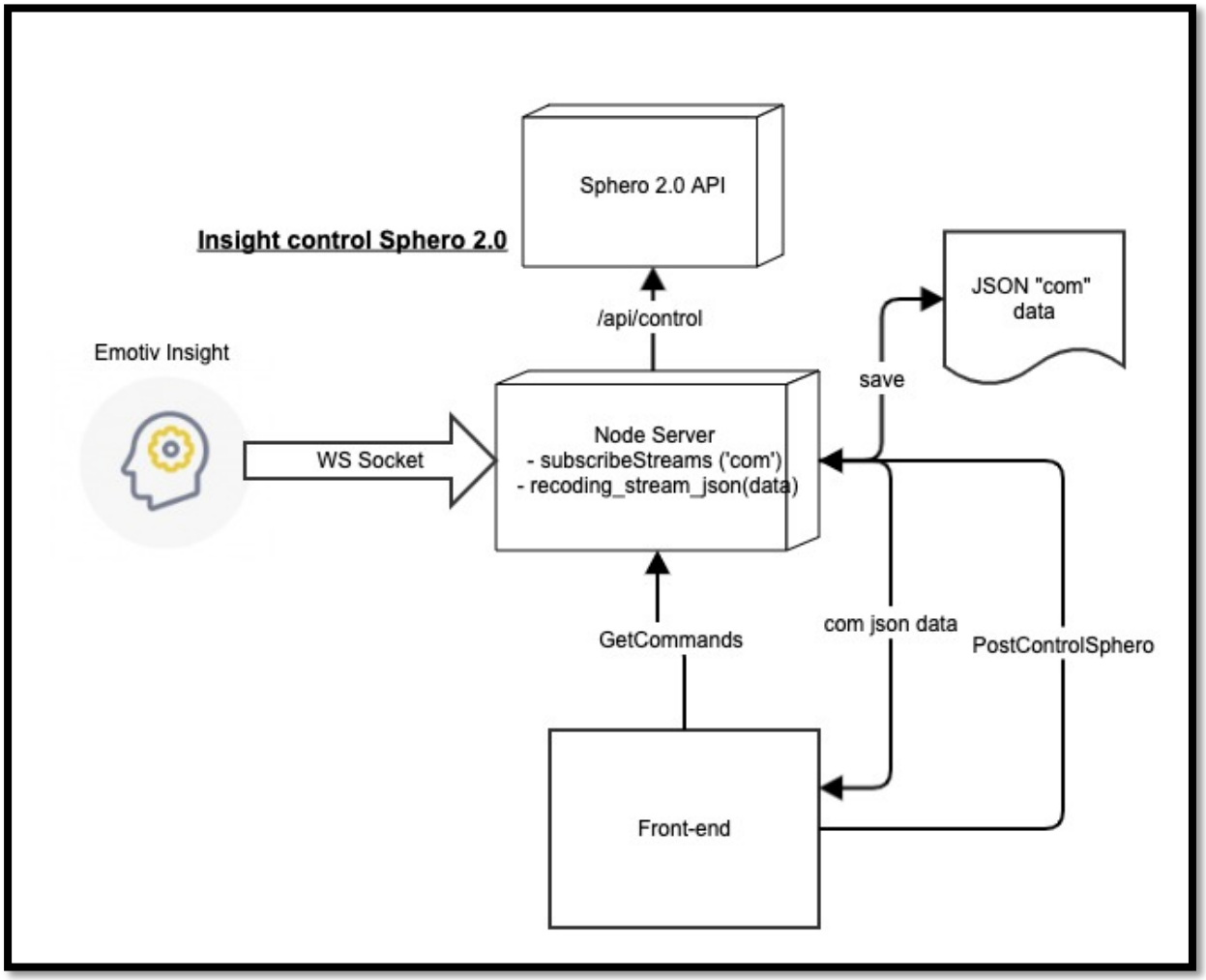


Figure 24 System architecture of InsightControlSphero2

6.2.3 Received data from Emotiv headset

By using subscribeStream('com') from Cortex, the received data from headset is in the following structure. The implemented model saves the data into info.json, see it in Github.com.


```
[
  "{\"id\":5,\"jsonrpc\":\"2.0\",\"result\":{\"failure\":[],\"success\":[{\"cols\":[\"act\",\"pow\"],\"sid\":\"7f9526e5-11a7-4e84-aaf2-d0bc677a15a6\",\"streamName\":\"com\"}]}}",
   "{\"com\":[\"push\",0.33590719771687666],\"sid\":\"281493ec-2a92-4f47-b62b-665e581d0363\",\"time\":1569308127.049}",
  "{\"com\":[\"push\",0.15671420820060034],\"sid\":\"281493ec-2a92-4f47-b62b-665e581d0363\",\"time\":1569308127.1753}",
  "{\"com\":[\"neutral\",0],\"sid\":\"281493ec-2a92-4f47-b62b-665e581d0363\",\"time\":1569308127.3013}",
]
```


Each output can be PUSH, PULL or NEUTRAL with the following format:

{

Com: ["push", 0.15671420820060034],

Sid: "",

Time: 1569308127.1753

}

The front-end requests streamed data for every 3 seconds the receive data are mixing of push, pull and neutral. This is because, there are some overlaps between those three commands for the training profile. So, it is decided to analyse for the majority command as an output command to post to Sphero 2 API. The following function is used to analyse the list of received commands.

```
function analyseMentalCommands(mentalCommands){
  var analyse_commands = {
    push : { score: 0, num: 1},
    pull : { score: 0, num: -1}
  }
  if (mentalCommands.length > 0){
    console.log(mentalCommands);
    var sc1 = mentalCommands.filter(x => x==analyse_commands.push.num).length;
```

```
    console.log(sc1);
    analyse_commands.push.score = sc1/mentalCommands.length;

    var sc2 = mentalCommands.filter(x => x==analyse_commands.pull.num).length;
    analyse_commands.pull.score = sc2/mentalCommands.length;
  }

  return analyse_commands;
}
```

It calculates the score of PUSH vs PULL to return one command from a raw of data as shown in Figure25.

```
[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,-1,-1,-1,-1,-1,-1,-1]
[-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1]
[1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0]
```

Figure 25 Mental commands received from Insight

Figure25 shows that the first row, an array of 0 (neutral) and -1 (pull). Secondly, the result is all (-1) mean for command PULL. Finally, the last array is mixing PUSH (1) then NEUTRAL (0) then PUSH and some other NEUTRAL (0). So, each array will be used to calculate the scores as following:

1. {push: {score: 0, num: 1}, pull: {score:7/39, num: -1} } => output: PULL (-1)
2. {push: {score: 0, num: 1}, pull: {score:39/39, num:-1} } => output: PULL(-1)
3. {push: {score: 15/39, num: 1}, pull: {score:0, num:-1} } => output: PUSH(1)

6.2.4 Back-end, node server

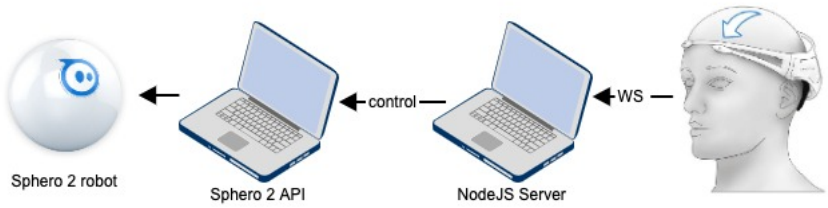


Figure 26 Insight control Sphero2 via NodeJS

6.2.4.1 Start server and streaming 'com' data

This experiment is using express server with Node 6.x, it starts streaming data from Emotiv headset while the server start. In the meantime, the server tries to connect to headset and wait for

command sending from client to post to Sphero. On the other hand, server should analyse the streamed data from headset and post to Sphero API directly. However, it cannot be done in a very short time because there are some complex tasks with asynchronous data from Insight headset. So, the purpose of this study is to use mental commands via EmotivBCI to control Sphero and it is working see the demo and the repository in Github.com about EEG Brain Signals, Machine Learning to control Sphero 2.

```
var cortex = require('./lib/cortex.js');


// start server on the specified port and binding host
app.listen(appEnv.port, '0.0.0.0', function() {

  // print a message when the server starts listening
  console.log("server starting on " + appEnv.url);
  cortex.getCommands();
});
```

6.2.4.2 Endpoints implemented on Node Server

GET, /eeg/commands/

This endpoint is used to get streamed data from JSON file, the file will be rewritten for every 10 seconds. It means that the json file was appended for every millisecond streaming from headset. Hence, the testing is being set for three seconds to get the new streamed commands. This endpoint does not get all data in info.json to client but instead, it queries for only the recent data not all of ten seconds data. As shown in the below figure, a millisecond it can produce eight lines of mental commands, so the json file will be 10*1000*8=80,000 lines. To do this experiment, it is querying only five milliseconds. Therefore, it analyses the output for 40 lines to get the most majority command to post to Sphero 2 API.

```
function getAllCommandsFromJson(callback){


try{
  var fs = require("fs");
  // Get content from file
  var contents = fs.readFileSync("./lib/info.json");
  // Define to JSON type
  var jsonContent = JSON.parse(contents);
  // Get Value from JSON
```

```
  callback(contents);
} catch(error){
  if (error != "")
    callback("err");
}

}

// get all data from info.json
app.get('/eeg/commands', function(req, res){
  getAllCommandsFromJson(function(data){
    res.send(data);
    res.end();
  });
});
```

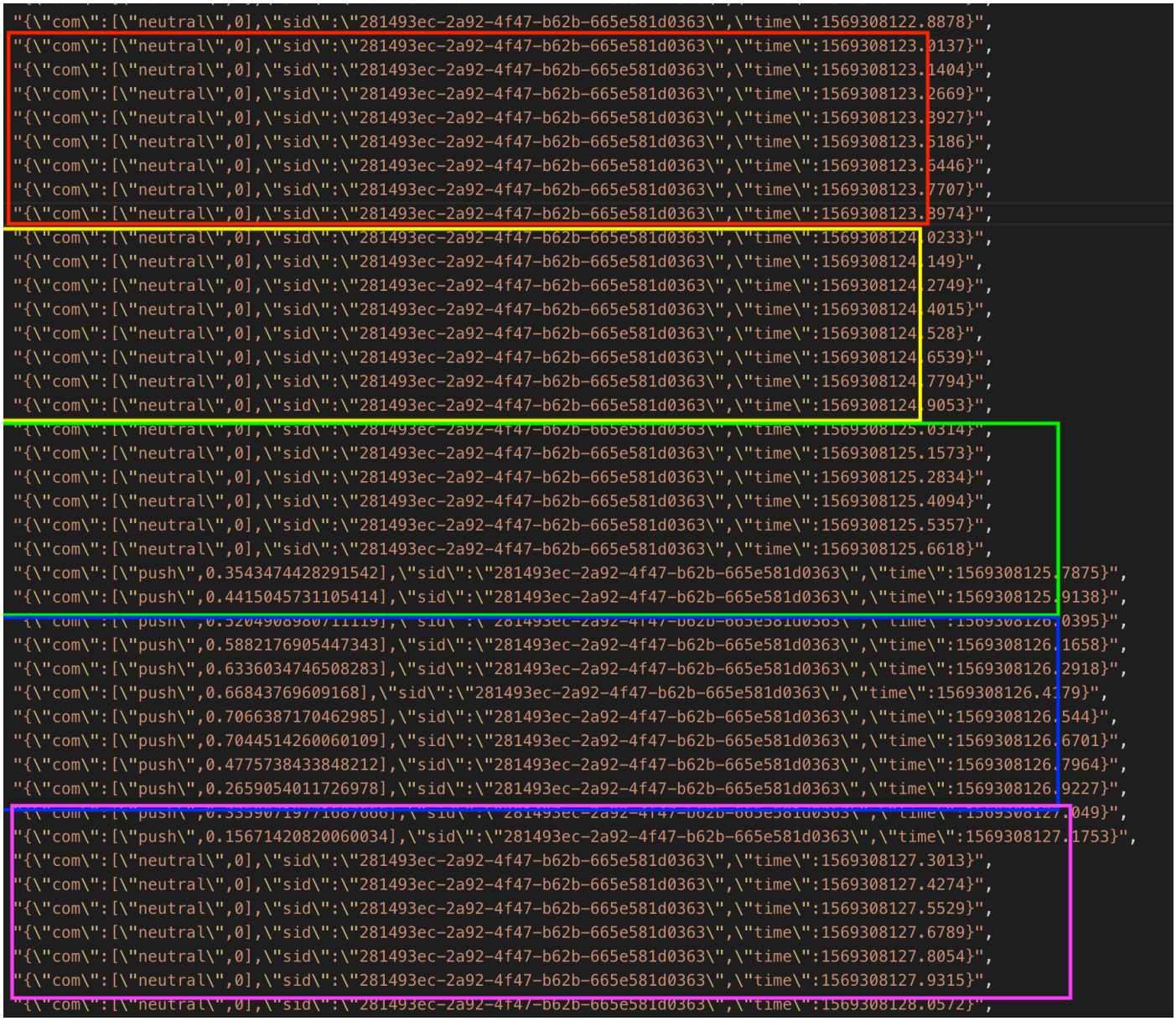


Figure 27 every millisecond it produces 8 records of commands

6.2.5 Front-end, a web page to allow user testing with Sphero 2

This page is used to display the outputs from Insight headset to control Sphero 2. It is using setTimeout to get streamed data for every three seconds. It consists four buttons such as SAVE, START LIVE, PUSH, PULL with five different columns. User needs to click on START LIVE to see the experiments, it needs to start Sphero 2 API too. PUSH and PULL are used to test the mental command by clicking a button to see what command came from Insight. For example, user intents to click on button PUSH and that user will think about PUSH action from the training then user can see whether the result is correct or not. However, it is sometime hard to use button PUSH and PULL to measure the experiment because as already stated about the Cortex is working extremely fast, so the result is always come after. Consequently, it is recommended to use LIVE to test the stimulus.

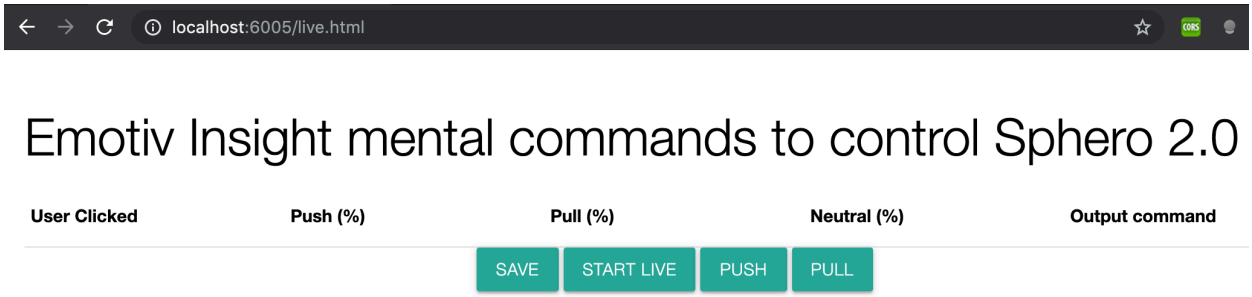


Figure 28 Live stream by using ajax to get the mental command for every 3s

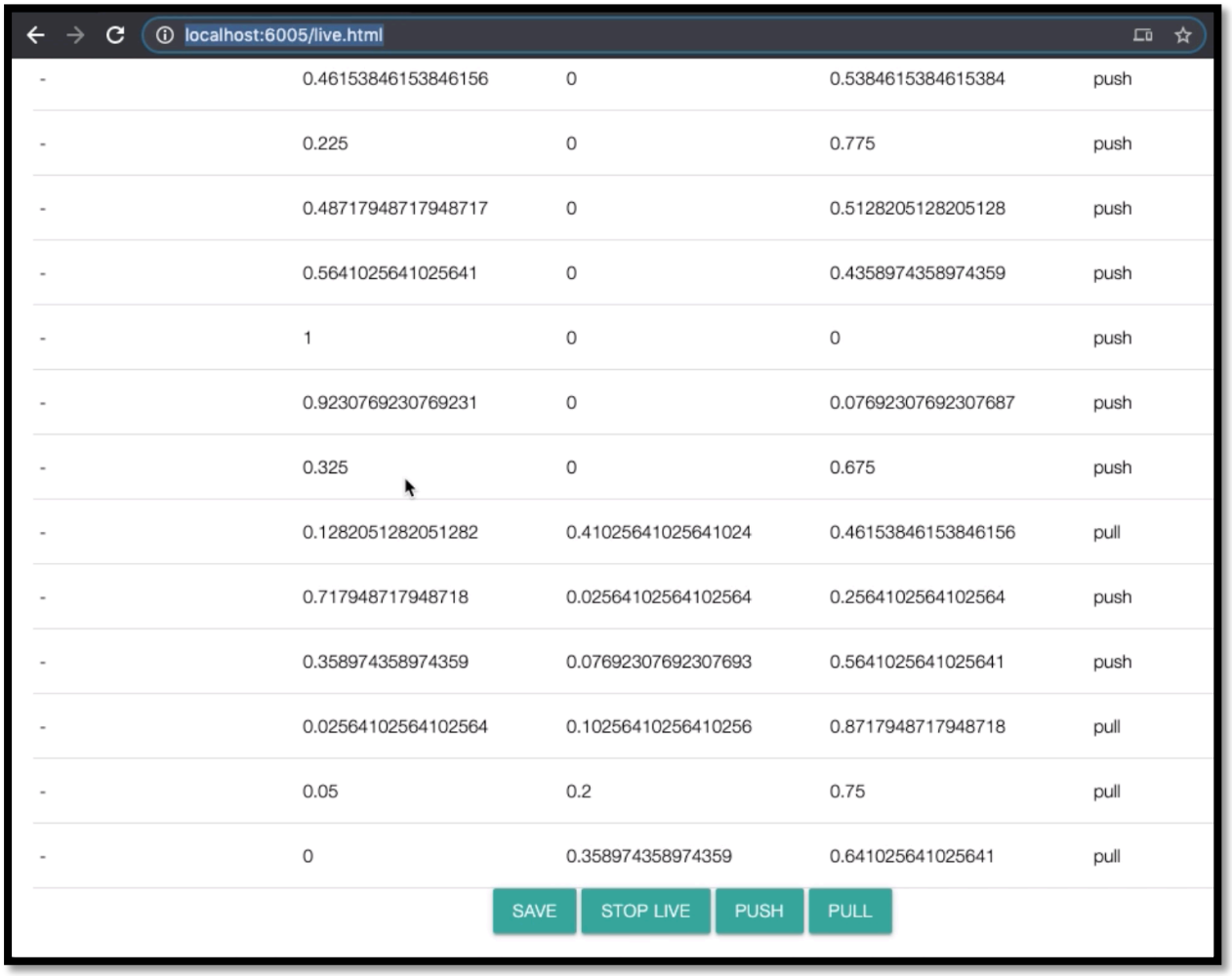


Figure 29 Ajax in front-end updates for every 3 seconds

6.2.6 Connect to Sphero 2 API

Sphero 2 API has been experimented by Mr. Miller Wang during his internship at Launchpad Greenwood of Deakin. He has done the endpoint ('/api/control/') in NodeJS to control robot go forward (1) and backward (-1), another endpoint is to change robot colour.

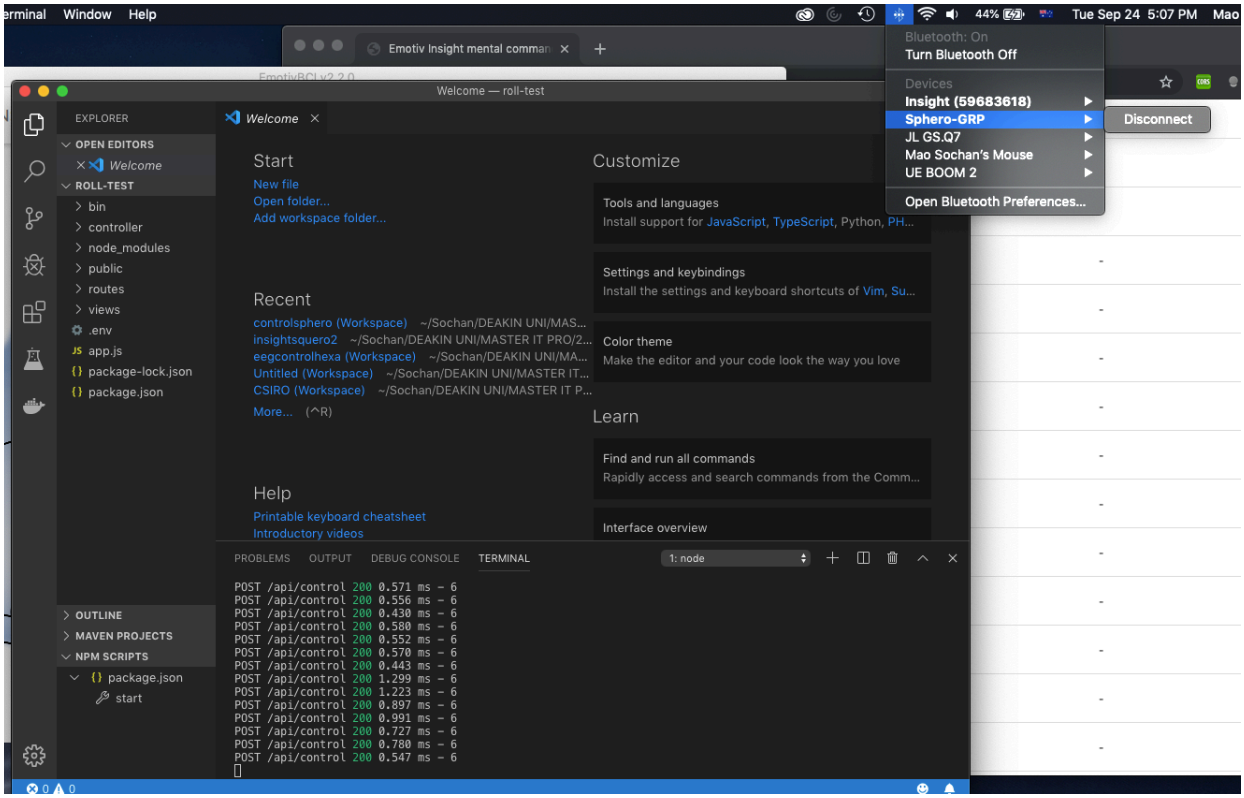


Figure 30 Connect Sphero 2 from NodeJS Server

6.3 Set up Sphero 2

To setup Sphero 2, see the instruction here. It can support various operating systems such as MAC OSX, Windows, Linux-Ubuntu. It is working with NodeJS, first to run the command to install NodeJS Serialport module “npm install sphero serialport”. After running this command, developer can see spher folder under node_modules with example to use its API. However, at the moment there will be an error about Serialport which can be solved by changing /node_modules/sphero/lib/adaptors/serialport.js with the below script at line 55.

```
//port = this.serialport = new serialport.SerialPort(this.conn, {});
port = this.serialport = new serialport(this.conn, {});
```

During the testing, sometimes it cannot open the port for Sphero. It may be conflicted with some open applications. For instance, here it is testing with Mac OSX, at first it shows the error “Resource busy, cannot open /dev/tty.Sphero-GRP-AMP-SPP, …”, the port may be in used.

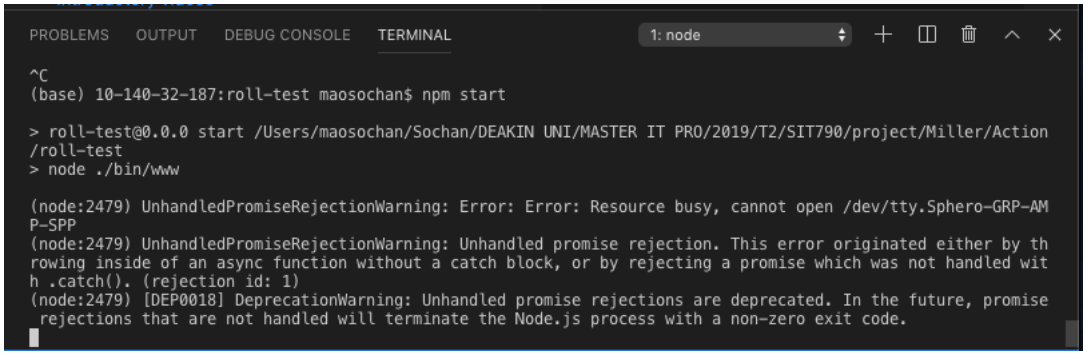


Figure 31 error about resource busy, please close some open applications and try again

6.4 Result and evaluation

Recap about the stimuli, it is using EmotivBCI to train mental commands to control Sphero2 with NodeJS. Two mental commands were trained via EmotivBCI for PUSH and PULL. As shown the below figure, one Neutral training was done, 5 Push trainings and 5 Pull trainings. It is working fine during the testing by seeing the Sphero 2 was move forward or backward which was controlled from Insight headset with displaying the output command on a webpage, please see the recorded videos Insight control Sphero2 with NodeJS and Displaying mental commands with EmotivBCI LIVE Mode.

Figure 32 Trained profile via EmotivBCI

6.4.1 Errors of output mental commands

Looking at the raw data which received from Insight for each mental command, it looks complicated See Figure33, it is curious to know about the algorithms that EmotivBCI is using. Furthermore, it was analysed by looking at their values, it looks confusing that the values of the received mental commands are not categized in a well format see the table below which it was copied from Figure33 into Microsoft Excel. Moreover, Table3 is showing that PULL has high values while PUSH never reach 0.5. The table is presenting that three commands of PULL with very low values should be clean up in the profile training that is causing the confusion. Hence, it is not clear about algorithms of EmotivBCI is using it cannot express about why those three commands of PULL are there. Even though, the experiments are showing almost correct that it can estimate about 90% to match with what user thought in his mind but it is 15% error that will not be accepted. EmotivBCI should be change its algorithms for its Machine Learning accordingly. 15% error is huge for ICT industrials, it cannot be used for real-time applications which need much precise, for instance flight control application or auto-drive applications. On the other hand, Emotiv BCI may work well with other high-performance headset such as EPOC which has more channels than Insight which has only 5 channels. Another problem may be related to the quality of contact electrodes during the profile training and testing which most of the time it got only 80% or 70%. If it is in a debate, there may be someone that would say that those errors may be caused by the trainers themselves. It will not be acceptable if someone raise something like that, Machine Learning must be smart to filter these errors during the trainings and also can feedback to the user about those error to never accept or it should not show the button accept for any nonsense training, for instance it was showing “reject” or “accept” while it finishes the training even the training quality was 0% matched goal, that is another mistake to allow the user accept some unqualified training experience.

Table 3 Analyse values of mental commands with some unaccepted errors

data	No	Command	Value
"{\"com\":[\"push\",0.00968565722498843],	8	push	0.00968565722498843
"{\"com\":[\"push\",0.0544843193724],\"s:	5	push	0.05448431937240000
"{\"com\":[\"pull\",0.18332181065355505],	20	pull	0.18332181065355500
"{\"com\":[\"push\",0.29293124205960014],	4	push	0.29293124205960000
"{\"com\":[\"push\",0.33608337899746965],\"	6	push	0.33608337899746900
"{\"com\":[\"push\",0.29331782875878204],	7	push	0.33608337899746900
"{\"com\":[\"pull\",0.3552005614910729],\"s	9	pull	0.35520056149107200
"{\"com\":[\"push\",0.3668849036890958],\"s	1	push	0.36688490368909500
"{\"com\":[\"push\",0.4507335501229853],\	2	push	0.45073355012298500
"{\"com\":[\"pull\",0.47290922242319683],	10	pull	0.47290922242319600
"{\"com\":[\"push\",0.48656871899154885],	3	push	0.48656871899154800
"{\"com\":[\"pull\",0.5649030683028096],\	19	pull	0.56490306830280900
"{\"com\":[\"pull\",0.5671041129100832],\	11	pull	0.56710411291008300
"{\"com\":[\"pull\",0.5893391811781247],\	13	pull	0.58933918117812400
"{\"com\":[\"pull\",0.6314889979854026],\	12	pull	0.63148899798540200
"{\"com\":[\"pull\",0.653437832626289],\"	14	pull	0.65343783262628900
"{\"com\":[\"pull\",0.7078292956613912],\	15	pull	0.70782929566139100
"{\"com\":[\"pull\",0.7172945703979108],\	18	pull	0.71729457039791000
"{\"com\":[\"pull\",0.7344084824686534],\	16	pull	0.73440848246865300
"{\"com\":[\"pull\",0.7431653165503014],\	17	pull	0.74316531655030100

6.4.2 Taking 5 milliseconds is facing or eliminating the risks?

The implemented model is using only the last 5 milliseconds, it queries for only 40 lines of info.json based on the current time. The stimuli seem went well, it may be because of the implemented model toke only 5 milliseconds, it is about 40 lines of 80,000 lines to cook for an output mental command. Sometimes, those few errors would not among the selected 40 lines which is helping to reduce the fatal errors. However, the worst cases would be happening, those errors cannot be acceptable for the high precise applications or it cannot be used for real experiment application for taking care people or household robots because there are some risks, but it is sometime fine for toys or testings.

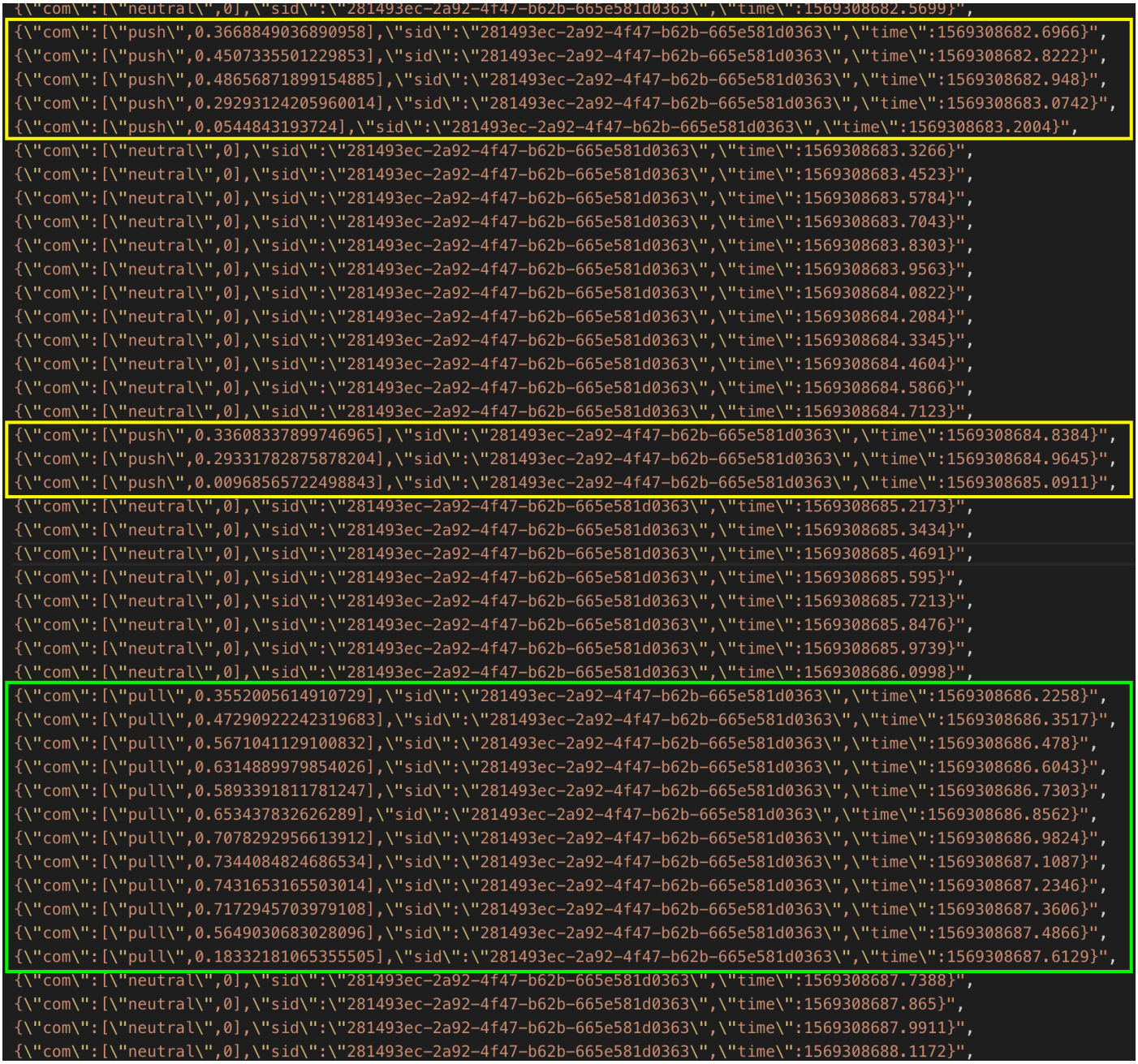


Figure 33 PUSH and PULL sample outputs

6.4.3 Testing to control Sphero 2 via implemented model

The model was integrated successfully and started testing. A video recording was done for a report, please see here. It was working, the Sphero moved accordingly, it went forward and backward. Sometimes, it is hard to prove that it is working but the implemented tool has a feature which user can test by thinking about one command then click on the button PUSH or PULL, see Figure29 about a web page which is created to see output mental command to control Sphero 2.

Figure 34 Emotiv Insight to control Sphero 2 with mental commands

7 Threats to validity

7.1 Experiment detail

Based on a very short period it was not tested by other users yet because it needs time to train mental commands per user. It should be at least 10 users to test the model then there will be more observations for the stimuli. These experiments were tested for two commands PUSH and PULL.

7.2 Train mental commands tips via EmotivBCI relates to STM or LTM

Another important observed from the experiment, it relates to the memory recall, to get the accurate responses, user should imagine what he or she has been thought during the profile training. For example, to call PUSH mental command, user should try to remember what he was thinking while training this PUSH command. To train a mental command, user can use any scenario he like the most to recognize a specific command. Consequently, there will be more difficult for multiple commands, user should remember what he was using of their minds during the profile training. To do so, it should be a clear plan about all comments then start to think about the right action of each command that should be easy for recall. Therefore, the most important thing to train mental commands via EmotivBCI is to use the right scenario to train the specific mental command. Emotiv expert has told in their website about the tip during train the command to get better result. For example, it is said to think about something very hot for PUSH during doing push command and imagine about something very cold for PULL. That will be working fine at the moment, it is about Short Term Memory but it may not work for Long Term Memory, for example people use the application not very often, they may forget what did they thought while they trained their commands, and it will be harder to recognize all commands. So, it is suggested to train with the right action and try to make it perfectly. There are nother better solution or may be efficient to user to remember their mental commands, the BCI application should ask user to write down about one mental command before training it, user can describe what they will use to train a command. In case user forget about what they have used during the BCI train, user can see the detail of their mental commands.

In addition, to get a good result for each mental command, use should concentrate on the current mental command and reflect what they are thinking at the time being trained one commands, user should not accept every result, sometimes, user do not think the right action, but the training result said it is a great training, but it is not the correct context, so make sure it is the right mind for the right mental command.

8 Conclusion and Future Research

To sum up, it is really appreciating to researchers who have been working hard in Electroencephalography (EEG) or Brain Computer Interface (BCI). This paper also mentioned about the background, the advantage of EEG. As shown in the reviews, there are numerous studies have been done to use EEG in different aspects. Therefore, doing something from mind is human dream for long time ago that will be a super magic if we just think and it happens. Moreover, this modern technology will change disability people life for ever because they can move their vehicles with their minds, they can talk to their friends and relatives, they lost their hands or legs but they still can control their computers for works, some disability people cannot talk due to some diseases but they still can express their brilliant ideas to the communities or the world. Sure, it is working, this stimulus is using Emotiv Insight to control Sphero robot to go forward or backward please see the videos and resources in Github.com. However, there are some issues as shown in the previous sections about 15% of fatal errors while it produced the mental commands, it may be caused by Machine Learning algorithms of EmotivBCI or Insight headset. Hence, Emotiv team should have a look at their Cortex SDK or EmotivBCI. Basically, to work with these kinds of technologies, Emotiv has introduced three ways, they are EmotivBCI (currently used in this paper), Node-Red Toolbox and SDK Cortex. This stimulus is using EmotivBCI and part of SDK Cortex V2 but there may be different outcomes to train BCI profile via SDK Cortex instead of EmotivBCI, it is a kind of unsupervised Machine Learning because it can train many profiles on the fly and upload to the Emotiv Cloud. After finishing this short research, we can see huge progress of BCI development because it is a lot easier than previous researches, for instance Gerad, C 2017, her project was very much similar to this one, it was about to use Emotiv EPOC to control objects but we can see her process are complicate with the old Emotiv SDK which mixed with some C++ libraries. Another part is about working with Robots, looking at Miller project, it requires only Sphero Serialport node module comparing to previous researches, they need to have Raspberry Pi to be able to connect to robots, for instance Casey, B 2015 introduce the use of Emotiv Insight to move BB-8 of Star war robot with IBM Bluemix.

Acknowledgement

Thanks Deakin University boards, Dr. Mohamed Abdelrazek, Dr. Alessio Bonti who are working hard to have such amazing technologies for students to learn. Furthermore, it is very appreciated to ICT students at Deakin who involved in this project.

References

Acı, Çİ, Kaya, M & Mishchenko, Y 2019, 'Distinguishing mental attention states of humans via an EEG-based passive BCI using machine learning methods', Expert Systems with Applications, vol. 134, pp. 153–166, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=aci&AN=137212264&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Agarwal, M. 2017, *A list of all public EEG-datasets*, Github, retrieved 22nd August 2019, < https://github.com/meagmohit/EEG-Datasets>.

Al Zoubi, O, Ki Wong, C, Kuplicki, RT, Yeh, H, Mayeli, A, Refai, H, Paulus, M & Bodurka, J 2018, 'Predicting age from brain EEG signals—A machine learning approach', Frontiers in Aging Neuroscience, vol. 10, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2018-33613-001&authtype=sso&custid=deakin&site=eds-live&scope=site>.

'A Review on Electroencephalogram Based Brain Computer Interface for Elderly Disabled' 2019, IEEE Access, Access, IEEE, p. 36380, viewed 31 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edseee&AN=edseee.8671703&site=eds-live&scope=site>.

Researchgate 2018, *What is the best open source software to analyse EEG signals?*, retrieved 22nd August 2019, < https://www.researchgate.net/post/What_is_the_best_open_source_software_to_analyse_EEG_signals2>.

Australian Network on Disability 2018, 'Disability Statistics', *AND.ORG.AU*, retrieved date 24th Sep 2019, <https://www.and.org.au/pages/disability-statistics.html>.

Binias, B, Myszor, D & Cyran, KA 2018, 'A Machine Learning Approach to the Detection of Pilot's Reaction to Unexpected Events Based on EEG Signals', Computational Intelligence & Neuroscience, pp. 1–9, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=128976674&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Bamatraf, S, Hussain, M, Aboalsamh, H, Qazi, E-U-H, Malik, AS, Amin, HU, Mathkour, H, Muhammad, G & Imran, HM 2016, 'A System for True and False Memory Prediction Based on 2D and 3D Educational Contents and EEG Brain Signals', COMPUTATIONAL INTELLIGENCE AND NEUROSCIENCE, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edswsc&AN=000368277600001&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Bergmann, J, Genc, E, Kohler, A, Singer, W & Pearson, J n.d., 'Neural Anatomy of Primary Visual Cortex Limits Visual Working Memory', CEREBRAL CORTEX, vol. 26, no. 1, pp. 43–50, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edswsc&AN=000370972500005&site=eds-live&scope=site>.

BioPortal 2019, 'Electroencephalogram', *National Cancer Institute Thesaurus*, 29 July 2019, retrieved date 1 August 2019, < http://bioportal.bioontology.org/ontologies/NCIT?p=classes&conceptid=http%3A%2F%2Fncicb.nci.nih.gov%2Fxml%2Fowl%2FEVS%2FThesaurus.owl%23C38054 >.

Bougrain, L 2017, 'Brain-Computer Interface', *Open Vibe*, retrieved date 25th September 2019, < https://archi2017.loria.fr/wp-content/uploads/2017/03/Laurent_Bougrain_cours_ARCHI_2017.pdf>.

Casey, B 2015, 'Use The Force – Move a Star Wars droid BB-8 with Your Mind', *IBM Cloud Blog*, retrieved date 30th September 2019, < https://www.ibm.com/blogs/cloud-archive/2015/12/the-force-bb8-emotiv-insight-bluemix/>.

Chaperon, B. & Chu, P. 2019, *Getting Started*, Emotiv, retrieved 02nd September 2019, < https://emotiv.gitbook.io/cortex-api/>.

Coroenne, M, Lely, L, Van Beers, P, Elbaz, M, Guillard, M, Leger, D, Chennaoui, M & Sauvet, F n.d., 'In flight automatic detection of pilot drowsiness using a single EEG channel. The French naval aviation experience', JOURNAL OF SLEEP RESEARCH, vol. 21, p. 205, viewed 28 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edswsc&AN=000307963201039&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Cowan, N 2019, 'Short-Term Memory Based on Activated Long-Term Memory: A Review in Response to Norris (2017)', Psychological Bulletin, vol. 145, no. 8, pp. 822–847, viewed 30 July

2019, <http://search.ebscohost.com/login.aspx?direct=true&db=eue&AN=137607740&site=eds-live&scope=site>.

Chen, J, Wang, H & Hua, C 2018, 'Assessment of driver drowsiness using electroencephalogram signals based on multiple functional brain networks', International Journal of Psychophysiology, vol. 133, pp. 120–130, viewed 31 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2018-51182-006&site=eds-live&scope=site>.

Child Mind Institute 2016, *EEG Data Download*, INDI, retrieved 7th August 2019, < http://fcon_1000.projects.nitrc.org/indi/cmi_eeg/eeg.html>.

Farnsworth, B. 2019, 'EEG (Electroencephalography): The Complete Pocket Guide', *Imotions*, retrieved date 20 August 2019, <https://imotions.com/blog/eeg/>.

Fernández, I, Sansevere, AJ, Gaínza-Lein, M, Kapur, K & Loddenkemper, T 2018, 'Machine Learning for Outcome Prediction in Electroencephalograph (EEG)-Monitored Children in the Intensive Care Unit', Journal Of Child Neurology, vol. 33, no. 8, pp. 546–553, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=mdc&AN=29756499&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Gates Bill 2007, 'A Robot in Every Home', Scientific American, vol. 296, no. 1, p. 58, viewed 26 September 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.26069115&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Github 2019, *eeg-classification*, retrieved 29th August 2019, < https://github.com/topics/eeg-classification>.

Gerad, C 2017, 'Node.js addon for the Emotiv C++ SDK', Github, retrieved date 30th August 2019, <https://github.com/charliegerard/Epoc.js>.

Grossman, D 2019, 'Elon Musk Wants to Upgrade Our Brains to Compete With AI', *Popular Mechanics*, retrieved date 20th September 2019, < https://www.popularmechanics.com/science/health/a28423949/elon-musk-neuralink/ >.

Haider, K.S., Jiang, A, Jamshed, M.A., Pervaiz, H & Mumtaz, S 2019, 'Performance Enhancement in P300 ERP Single Trial by Machine Learning Adaptive Denoising Mechanism' 2019, IEEE Networking Letters, Networking Letters, IEEE, IEEE Netw. Lett, no. 1, p. 26, viewed 31 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edseee&AN=edseee.8550648&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Hanslmayr, S & Staudigl, T 2014, 'How brain oscillations form memories — A processing based perspective on oscillatory subsequent memory effects', NeuroImage, vol. 85, no. Part 2, pp. 648–655, viewed 31 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edselp&AN=S1053811913006319&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Jaiswal, AK & Banka, H 2018, 'Epileptic seizure detection in EEG signal using machine learning techniques', Australasian Physical & Engineering Sciences In Medicine, no. 1, p. 81, viewed 29 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edsgao&AN=edsgcl.530943031&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Kiiski, H, Jollans, L, Donnchadha, SÓ, Nolan, H, Lonergan, R, Kelly, S, O'Brien, MC, Kinsella, K, Bramham, J, Burke, T, Hutchinson, M, Tubridy, N, Reilly, RB & Whelan, R 2018, 'Machine learning EEG to predict cognitive functioning and processing speed over a 2-year period in multiple sclerosis patients and controls', Brain Topography, vol. 31, no. 3, pp. 346–363, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2018-04209-001&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Kan, DPX, Croarkin, PE, Phang, CK & Lee, PF 2017, 'EEG Differences Between Eyes-Closed and Eyes-Open Conditions at the Resting Stage for Euthymic Participants', Neurophysiology, vol. 49, no. 6, pp. 432–440, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=129155164&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Kornell, N nkornell@gmail. co. 2015, 'If it is stored in my memory I will surely retrieve it: anatomy of a metacognitive belief', Metacognition & Learning, vol. 10, no. 2, pp. 279–292, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=eue&AN=103547077&site=eds-live&scope=site>.

Kevin, N 2019, 'Canadian missing teens revealed as suspects in Lucas Fowler and Chynna Deese murder', *ABC News,* 24 July 2019, retrieved date 31 July 2019, < https://www.abc.net.au/news/2019-07-24/mcleod-schmegelsky-suspects-in-fowler-deese-canada-murder/11340738>.

Khandelwal, R., Mahajan, J., Bombatkar, U. and Badhe, S. (2016). Analysis of EEG Signals for Deception Detection. IJAREEIE, 5(2), pp.836-843.

Lai, Peng-Wen, Li-Wei Ko, Yukai Wang, and Chin-Teng Lin. 2017. "EEG-Based Assessment of Pilot Spatial Navigation on an Aviation Simulator." Journal of Science and Medicine in Sport 20 (Supplement 2): S37–38. doi:10.1016/j.jsams.2017.09.597.

Liu, Y. 2017, 'Op-Ed for the World Health Day 2017', *WHO*, retrieved date 30 August 2019, < http://www.wpro.who.int/cambodia/mediacentre/releases/20170407-whd/en/>.

Mumtaz, W, Ali, SSA, Yasin, MAM & Malik, AS 2018, 'A machine learning framework involving EEG-based functional connectivity to diagnose major depressive disorder (MDD)', Medical & Biological Engineering & Computing, vol. 56, no. 2, pp. 233–246, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=127735945&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Nobuhiro Yamagata, Toshiharu Ichinose, Yoshinori Aso, Plaçais, P-Y, Friedrich, AB, Sima, RJ, Preat, T, Rubin, GM & Hiromu Tanimoto 2015, 'Distinct dopamine neurons mediate reward signals for short- and long-term memories', Proceedings of the National Academy of Sciences of the United States of America, vol. 112, no. 2, pp. 578–583, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=103328292&site=eds-live&scope=site>.

Nie, J, Zhang, Z, Wang, B, Li, H, Xu, J, Wu, S, Zhu, C, Yang, X, Liu, B, Wu, Y, Tan, S, Wen, Z, Zheng, J, Shu, S & Ma, L 2019, 'Different memory patterns of digits: a functional MRI study', Journal of Biomedical Science, vol. 26, no. 1, p. N.PAG, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=135054653&site=eds-live&scope=site>.

Noh, E, Liao, K, Mollison, MV, Curran, T & de Sa, VR n.d., 'Single-trial EEG analysis predicts memory retrieval and reveals source-dependent differences', Frontiers in Human Neuroscience, vol. 12, viewed 26 September 2019,

<http://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-85054826533&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Peker, M 2016, 'An efficient sleep scoring system based on EEG signal using complex-valued machine learning algorithms', Neurocomputing: An International Journal, vol. 207, pp. 165–177, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2016-26301-001&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Priyanka A. Abhang, Bharti W. Gawali, Suresh C. Mehrotra 2016, *Introduction to EEG- and Speech-Based Emotion Recognition*, Elsevier, Aurangabad, India.

Reggente, N, Cohen, MS, Zheng, ZS, Castel, AD, Knowlton, BJ & Rissman, J 2018, 'Memory Recall for High Reward Value Items Correlates With Individual Differences in White Matter Pathways Associated With Reward Processing and Fronto-Temporal Communication', Frontiers in Human Neuroscience, viewed 28 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edsgao&AN=edsgcl.542898200&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Sauvet, F, Bougard, C, Coroenne, M, Lely, L, Van Beers, P, Elbaz, M, Guillard, M, Leger, D & Chennaoui, M 2014, 'In-Flight Automatic Detection of Vigilance States Using a Single EEG Channel', IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, vol. 61, no. 12, pp. 2840–2847, viewed 28 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edswsc&AN=000345501000003&authtype=sso&custid=deakin&site=eds-live&scope=site>.

SCCN 2019, *EEG / ERP data available for free public download (updated 2019)*, University of California San Diego, retrieved 15th August 2019, < https://sccn.ucsd.edu/~arno/fam2data/publicly_available_EEG_data.html>.

Schirrmeister, RT, Springenberg, JT, Fiederer, LDJ, Glasstetter, M, Eggensperger, K, Tangermann, M, Hutter, F, Burgard, W & Ball, T 2017, 'Deep learning with convolutional neural networks for EEG decoding and visualization', Human Brain Mapping, vol. 38, no. 11, pp. 5391–5420, viewed 27 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=mdc&AN=28782865&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Shankland, S 2019, 'Elon Musk says Neuralink plans 2020 human test of brain-computer interface', *CNET,* 17 July 2019, retrieved date 31 July 2019, < https://www.cnet.com/news/elon-musk-neuralink-works-monkeys-human-test-brain-computer-interface-in-2020/>.

Sharma, M, Achuth, PV, Deb, D, Puthankattil, SD & Acharya, UR 2018, 'An automated diagnosis of depression using three-channel bandwidth-duration localized wavelet filter bank with EEG signals', Cognitive Systems Research, vol. 52, pp. 508–520, viewed 29 August 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edselp&AN=S1389041718302298&authtype=sso&custid=deakin&site=eds-live&scope=site>.

Polanía, R, Paulus, W & Nitsche, MA 2012, 'Noninvasively Decoding the Contents of Visual Working Memory in the Human Prefrontal Cortex within High-gamma Oscillatory Patterns', Journal of Cognitive Neuroscience, vol. 24, no. 2, pp. 304–314, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=70257173&site=eds-live&scope=site>.

TISO, G 2018, 'On Remembering to Back-Up Grandpa', Overland, no. 232, pp. 69–70, viewed 30 July 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=hus&AN=132883705&site=eds-live&scope=site>.

Tuck 2019, 'Stages of Sleep and Sleep Cycles', *Tuck*, retrieved date 30th August 2019, updated 9th August 2019, < https://www.tuck.com/stages/>.

Tuh EEG 2019, *Temple University Hospital EEG (TUH EEG) Resources,* Neural Engineering Data Consortium, retrieved 22nd August 2019, < https://www.isip.piconepress.com/projects/tuh_eeg/>.

Valizadeh, SA, Riener, R, Elmer, S & Jäncke, L 2019, 'Decrypting the electrophysiological individuality of the human brain: Identification of individuals based on resting-state EEG activity', NeuroImage, vol. 197, pp. 470–481, viewed 1 September 2019, <http://search.ebscohost.com/login.aspx?direct=true&db=edselp&AN=S1053811919302915&authtype=sso&custid=deakin&site=eds-live&scope=site>.